THE UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR Nels Leonard Drugge

TITLE OF THESIS The Facilitating Effect of Selected Analogies on Understanding of Scientific Explanations.

DEGREE FOR WHICH THESIS WAS PRESENTED Doctor of Philosophy

YEAR THIS DEGREE GRANTED 1976

THE UNIVERSITY OF ALBERTA

THE FACILITATING EFFECT OF SELECTED ANALOGIES ON UNDERSTANDING OF SCIENTIFIC EXPLANATIONS

by

© NELS LEONARD DRUGGE

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF SECONDARY EDUCATION

EDMONTON, ALBERTA

FALL , 1976

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled THE FACILITATING EFFECT OF SELECTED ANALOGIES ON UNDERSTANDING OF SCIENTIFIC EXPLANATIONS submitted by NELS LEONARD DRUGGE in partial fulfilment of the requirements for the degree of Doctor of Philosophy.

ABSTRACT

This study was designed to investigate the pedagogical use of verbal and physical analogies in scientific explanations of chemical concepts. A rationale was developed for the pedagogical use of analogies and it was hypothesized that the use of a verbal or a physical analogy in a scientific explanation increases the student's immediate comprehension of the scientific explanation over that attained when the scientific explanation is presented without the use of one of these types of analogy. This hypothesis was tested in three different experiments using 814 eighth grade subjects, 180 ninth grade subjects and 1258 tenth grade subjects. In all experiments, one scientific explanation and its associated criterion test designed to measure the subject's comprehension of the scientific explanation were administered to each subject. In addition, in two of the experiments, the primary field of a verbal analogy also accompanied the scientific explanation, except in the case of control group subjects who received only the scientific explanations. In the other experiment the primary field of a physical analogy was demonstrated to experimental subjects. The criterion mean scores of the experimental group which was administered the analogy and the control group which read only the scientific explanation were compared in all cases. The above hypothesis was tested in five cases for concrete verbal analogies and in two cases for conceptual verbal analogies and

physical analogies. In no case did the use of a concrete or a conceptual verbal analogy in a scientific explanation increase immediate comprehension over that of the control group. This finding was substantiated for different sexes, the five formats in which the primary field was presented, topics of the scientific explanations, length of scientific explanations (between 150 and 815 words), grade levels of the subjects (grades 8,9, and 10), and levels of understanding of the analogy. Three treatment means were significantly less that the corresponding control group means when concrete verbal analogies were used. This appeared to be a result of a topic x format x length of scientific explanation interaction in one of the experiments. On the other hand,when a physical analogy was used in a scientific explanation, immediate comprehension was significantly greater than that of the control group in one of two cases. Analysis of the scientific explanations indicated that the one scientific explanation for which there was a significant difference between treatment and control groups was relatively more complex than the other.

ACKNOWLEDGEMENTS

I am deeply indebted to Dr. Heidi Kass for her valuable suggestions, patient guidance and the encouragement she has given me during the design and execution of this study. I should also like to thank Dr. M.A. Nay, Dr. W. Brouwer, and Dr. S.Hunka for their penetrating comments and advice on the design of the study. I am also indebted to Dr. S.G. Davis and Mr. F. Jenkins for the assistance they so generously gave in revising the criterion tests used in this study.

Without the cooperation of the Edmonton Public School Board, the Edmonton Separate School Board, the St. Albert Separate School Board, and the Vancouver School Board, their administrators, and the teachers and students of the schools, this study would not have been possible. I wish to express my sincere gratitude to administrators, teachers and students for their outstanding cooperation in participating in this study.

Finally, I would like to thank my wife, Pat, for her encouragement and support during the course of this study and my daughters, Heather and Carolyn, for their patience and understanding.

TABLE OF CONTENTS

CHAPTER		PAGE

CHAPTER PAGE

CHAPTER	PAGE

LIST OF TABLES

CHAPTER I

INTRODUCTION

In man's attempt to understand his universe, he must use the mental equipment which is available to him. It seems improbable that man can comprehend new information except on the basis of the mental constructs he already possesses, or those which he can create through manipulation of existing constructs in his cognitive structure. Hence, understanding of new learning material is dependent on the use of familiar mental constructs.

Scholars (Belth, 1975; Bruner, 1973; Gendlin, 1962; James, 1892; Lazslo, 1972; Moses, 1973; Schon, 1963; Templeton, 1973; Vaihinger, 1924) have argued that new learning material is understood through the use of models based on mental constructs in the cognitive structure. These scholars hypothesize that new learning material is understood by employing familiar cognitive constructs which become models through which the new learning material can be analyzed. They claim that the process of understanding consists of juxtaposing the unfamiliar new learning material system to a familiar system of cognitive constructs and analyzing the elements and/or relations of the unfamiliar system in terms of the familiar system. The result of juxtaposing two systems for the purpose of analyzing the less familiar system in terms of the familiar system may be an analogy.

The process of analyzing two structurally similar systems by comparing point for point the elements and/or relations of the two systems and mapping the elements and/or relations of the two systems onto each other is referred to as the process of analogizing. Since, in the process of understanding, an analogy is established between existing cognitive constructs and the new learning material and the analogy is analyzed through the process of analogizing, comprehension of new learning material is inextricably linked to existing cognitive constructs.

Oppenheimer points out this fundamental role analogy plays in thought:

> . . . analogy is inevitable in human thought, because we come to new things in science with what equipment we have, which is how we have learned to think and, above all, how we have learned to think about the relatedness of things. We cannot, coming into something new, deal with it except in terms of the familiar and the old-fashioned.
> (Oppenheimer, 1956:129)

Belth (1975:133) points out the dependency of understanding on existing cognitive structure when he says that since interconnectedness, meaning, tendencies, lawfulness or patterns lie not in the events themselves but in the available mental models, understanding is dependent on the available mental models.

Evidence for the belief that understanding is dependent on linking new learning material to existing cognitive constructs is found in the ubiquitous use of analogies in search for understanding in a number of fields of human endeavour. In religion, an analogy is established between man and God to enable people to understand some of the characteristics attributed to God (Anderson, 1962). Philosophers employ analogies to explain obtuse concepts to the neophyte. Authors employ analogies in the form of fables and allegories to enable the reader to understand their message (Chemical Education Material Study, 1960). In advising students on writing essays, Bilsky (1963:73) claims, "When you compare an abstract idea with something that is concrete and familiar to your reader, you enable him to see more clearly what you are talking about since you present him with a picture." Kauzman remarks on the use of analogies in science to understand scientific theories:

> Analogies are very helpful to most people in understanding old theories and in developing new ones. It is always easier to arrange new ideas in the framework of what one already knows than it is to build upon entirely new systems of ideas from bare logical essentials. Furthermore, analogies provide 'insight'--a very valuable,thing in itself. (Kauzman, 1957:6)

In the context of teaching, Asimov (1959:535) claims that the judicious use of analogies in the introduction of new concepts is an aid to understanding. Kamenetskii (1966:132) claims, "Every pedagogue knows from experience that an appropriate choice of analogies in the explanation of any given subject makes it easier understood by students." It would appear that the pervasive use of analogies in the various fields to effect under-

standing indicates a belief that understanding is dependent on the use of analogy to link new learning material to existing cognitive structure.

The belief of science educators in the power of analogy to effect understanding is indicated by the widespread use of analogies in science textbooks. In a survey of two hundred children's science textbooks, Beeler (1954) found eight thousand sixty-two analogies. The frequency of occurrence was one analogy per eight hundred and thirty-five words. Scott (1964) performed a similar study on first year college chemistry textbooks. He found the frequency of use of analogies increased over the period 1930-1960 with the most significant increase from 1950 to 1960. Scott found an average of eleven elaborated analogies per book with a range of five to twenty-six in total.

In view of the faith which educators have in the power of analogy as an explanatory device to effect understanding, and because of the relative paucity of research to substantiate this faith, the present study was designed to evaluate the effectiveness of analogy in effecting understanding of written scientific explanation in a conventional school setting.

STATEMENT OF THE PROBLEM

The problem to which this study is directed is: does the use of an analogy in a written scientific explanation have a measurable effect upon the learner's immediate comprehension of the explanation when it is read?

NEED FOR THE STUDY

It has been suggested that analogies are extensively used in school science textbooks (Beeler, 1954; Scott, 1964) and by classroom teachers (Kamenetskii, 1966) to aid the student in understanding explanations of scientific phenomena. However, comparatively little attempt has been made to investigate the psychological basis for the pedagogical use of analogy or to evaluate whether or not the use of analogy in explanations does in fact facilitate student understanding of scientific phenomena. Dowell (1968) attempted to determine whether the use of visual pictorial analogies in classroom teaching aid in increasing student comprehension of the biological concept of function and found no increase in comprehension on an achievement test. Scott (1964) found that most analogies used in chemistry textbooks were verbal analogies. Physical analogies were the second most frequent type of analogy employed by authors of chemistry textbooks.

Since chemistry textbook authors frequently employ verbal and physical analogies to effect understanding of explanations in chemistry, there appears to be a need to determine whether or not the use of verbal and physical analogies in chemical explanations aids the learner in understanding explanations of chemical phenomena and to develop a rationale for the pedagogical use of analogies. These are the objectives of the present study.

A brief outline for the rationale for the pedagogical use of analogy is presented in a subsequent section of this chapter. In Chapter II empirical studies related to the rationale are reviewed and the psychological mechanisms of the use of analogy are surveyed and related to Ausubel's theory of Meaningful Learning. In Chapter III the designs of the three experiments which comprise the present study are presented. The results of the three experiments and a discussion of the results are presented in Chapter IV. Chapter V presents a summary of the results, implications for science teaching and suggestions for further research.

Because the language required to discuss analogies tends to be somewhat technical and unusual, a number of terms will be defined before proceeding with the development of the present study. The terms fall into two categories. Those presented first deal with the language of analogy and those which follow are the operational definitions required for the present study.

DEFINITION OF TERMS

(In Logical Order of Development)

Terms Related to Analogy

System: A system is a complex of interacting elements

Analogy: An analogy is a relation between two systems such that groups of elements of one system have similar relations to corresponding groups of elements of a second system. For pairs of elements, these relations may be stated symbolically as a:b::x:y which is read "a" is related to "b" in a similar way as "x" is related to "y" or simply "a" is to "b" as "x" is to "y". The elements "a", "b", "x", "y" are called the ANALOGATES. The common relation between "a" and "b" and "x" and "y" is called the ANALOGON.

Of the two systems employed in an analogy, the system whose elements and relations are most familiar to the learner is called the primary field. The less familiar system is called the secondary field. If the elements "a" and "b" and the relation between these elements are known by the learner, then "a" and "b" are called the primary analogates and together with their analogon they are part of the primary field of the analogy. On the other hand, the analogates "x" and "y" which exist in the new material to be learned are called the secondary analogates and together with their analogon are part of the secondary field of the analogy.

Operational Definitions

Scientific Discourse: A scientific discourse is any series of written symbols that is organized into one or more syntactic expressions consistent with the rules of grammar of the English language or with the rules of mathematics and whose principal content is scientific in nature.

Argument: An argument is a discourse in which some statements are supplied as reasons for other statements.

Scientific Explanation: A scientific explanation is a scientific discourse employing the form of an argument.

Hypothetical Syllogism: A hypothetical syllogism consists of a number of statements of the form: "if. . . , then. . . ." The statements are connected to each other in such a way that the consequent of the n^{th} statement becomes the antecedent of the $n + 1^{th}$ statement. In symbolic form the hypothetical syllogism may be represented as:

$$
\begin{array}{c}
p \longrightarrow q \\
q \longrightarrow r \\
r \longrightarrow s \\
\hline
p \longrightarrow s
\end{array}
$$

Argument Rank: The argument rank is the number of "If. . . , then. . . ." statements chained together in a hypothetical syllogism. For example,

the argument illustrated above in the definition of "hypothetical syllogism" has an argument rank of three.

Passage: A passage consists of one of the following units:

(a) a scientific explanation,

(b) a scientific explanation and its corresponding primary field.

Criterion Test: The criterion test is a test consisting of multiple choice items pertaining to the content of the scientific explanation.

Criterion Score: The criterion score is the total number of correct responses on the criterion test.

Comprehension: Comprehension is understanding of the scientific explanation as indicated by the criterion score.

Analogy Test: An analogy test is a test consisting of multiple choice items pertaining to the relations between the scientific explanation and the primary field of the analogy. Each item has one correct response and four distractors.

Analogy Score: The analogy score is the total number of correct responses on the analogy test.

Test Booklet: The test booklet consists of one passage and its corresponding criterion test, and, in those cases where it is relevant to the treatment, an analogy test.

EXPLANATION AND ANALOGY

The role of explanation in the development of knowledge is discussed in the present section followed by a discussion of the ways in which the use of analogy in classroom explanation is thought to facilitate understanding of new learning material and to nurture cognitive growth. Empirical and theoretical studies which are related to and form a basis for the claims made for the use of analogy in verbal explanation are reviewed in Chapter II.

Explanation

One of the pedagogical devices science teachers use to facilitate student understanding of scientific phenomena is verbal explanation. A distinction must be made between two kinds of explanation: pedagogical explanation and scientific explanation. The explanation offered by a teacher in explaining something to a student is different from the explanation offered by a scientist in his attempt to account for the way things behave. In the former case, the explainer's activity of explaining is not a matter of research, investigation, original theorizing and the like, but a matter of interpreting to someone else ordered knowledge which is the result of scientific investigation (Martin, 1970:14). Martin (1970:15) refers to the inquiry related explanation of the scientist as <u>explaining something</u> and the pedagogy-

related explanation of the teacher as <u>explaining something to someone</u>. In the present study, the words "explanation" and "explaining" should be interpreted in the pedagogical sense unless otherwise indicated. Having made this distinction, the objective of explanation must now be considered.

In the specific pedagogy-related sense, the objective of explanation is student understanding of the subject matter involved in the explanation. Martin (1970:153) defines understanding as "seeing" the relationships or connections among concepts. From the point of view of cognitive psychologists, relationships among concepts are "seen" or understood when a match can be established between the relationships in the cognitive structure and those in the subject material of the explanation (Lazslo, 1972). Piaget employs the biological concept of adaptation as a mechanism in the process whereby this match (i.e. understanding) is achieved. Adaptation involves the two complementary processes of "assimilation" and "accommodation". Assimilation is the process wherein a relation is set up between new learning material and the structure of the cognitive system. Accommodation is the process wherein the existing cognitive structure is modified to accept the relationships among the concepts of the new learning material. When new learning material is encountered it is assimilated to the existing cognitive structure if it is in some way relatable to it. The cognitive structure, on the other hand, must accommodate to incorporate the new learning material. When the two complementary processes of assimilation and accommodation reach a

state of equilibrium, understanding of the new learning material is effected since at this point a match between the structure of the new learning material and the cognitive structure is attained. After understanding is attained a process ensues in which the form of the new learning material is abstracted from its content. This abstracted form becomes available for understanding further new learning material.

Since understanding is the objective of explanation, the role of the explainer, according to the model outlined above, becomes one of presenting the new learning material in such a way that the processes of assimilation, accommodation and abstraction are facilitated. It has been proposed by a number of scholars that the use of analogy in an explanation may facilitate these processes. The mechanisms whereby analogy is thought to facilitate these processes are explored in the following sections.

Analogy and Assimilation

James (1892:323) has pointed out that one of the processes of thought which distinguishes man from animal is man's ability to use "association by similarity." He claims that this process enables man to abstract concepts from particular instances. James regards analogy functioning in this process as a heuristic device. According to James, scientific man deliberately accumulates all instances he can find which have any relation to a phenomenon; then, while holding these instances in his mind he abstracts the commonality from them. It appears that

James considers analogy as functioning in the assimilation process since the accumulation of cases can only be accomplished through assimilation to the cognitive structure. If a primary field of an analogy is presented to the learner which has similar relations to those in the new learning material, the step involving the gathering of similar cases may be facilitated. Furthermore, the supplying of a similar case may point out to the learner some aspect of the cognitive structure to which the new learning material may be assimilated.

Nagel also considers analogy as functioning in the assimilation process. He claims that analogies help to assimilate the new to the old (Nagel, 1961:46). In other words, analogy acts as a mechanism whereby new learning material may be assimilated to previously established cognitive structures. Vaihinger (1924) and Belth (1975) claim that not only are analogy and analogizing the mechanisms of the assimilation process, they are the only means whereby assimilation occurs. Vaihinger (1924:29) states, "Anyone acquainted with the mechanism of thought knows that all conception and cognition are based upon analogical apperceptions." Belth (1975:5) claims, ". . . the process of thinking is the process of analogizing--itself a process. . . ." While the claims of Vaihinger and Belth may be overstatements, they do illustrate the conviction that analogy and analogizing function in the assimilation process.

Another way the use of analogy in explanation may operate in the assimilation process is that it may prevent novel explanations

from appearing unrelatable to the learner's existing cognitive structure. Nagel (1961:46) recognizes this property of analogy when he states that analogies prevent novel explanatory premises from being radically unfamiliar. The role of analogy in this process may be that of a device which can focus on relations which are common to the cognitive structure and the new learning material. Assimilation can occur only if the learner perceives the new learning material as being related to his cognitive structure. When radically new material is presented to the learner much of it can not be understood since the learner does not have adequate cognitive structures to match with much of new learning material and the unmatchable portions are registered by the learner as "noise" (Dienes, 1963:63). The "noise" may tend to mask that part of the message which could ordinarily be assimilated and understood.

However, if an analogy which focuses on those relations which are common to the cognitive structure and the new learning material and de-emphasizes the unmatchable portions is used by the explainer, the learner may perceive the new learning material as being assimilable to his cognitive structure. Once intelligibility has been established between the parts of the new learning material for which a match can be made, the unmatchable portion may be dealt with through accommodation. Hence the use of analogy in an explanation may enable the learner to assimilate radically new learning material by acting as a focusing device and filtering out masking "noise". For example, consider the problem of explaining a scientific theory to someone who is not familiar

with it. Because theories are abstracted from specific instances and must be generalizable to further instances, their concepts and relations are abstract. The neophyte probably does not possess clearly defined relational concepts or rule-sets in his cognitive structure to match with the new learning material. If an explanation of the theory were to consist of presenting the theory in its most abstract form, those concepts and relations for which the learner had previously constructed adequate structures may be masked by noise from the unmatchable portion of the new learning material, with the result that the explanation would be registered as meaningless. Consequently, some device needs to be employed to separate the message or signal from the noise. This is usually done by presenting to the learner a model which is within his experience and which has relations among its elements similar to those in the theory. The function of the model is to remind the learner of, or provide him with, a structural framework or "system of categories" with which he is already familiar or with which he can with relatively little effort become familiar (Weller, 1970:118). The model, of course, is not isomorphic with the theory in all aspects but acts to filter selected intelligible relations from "noise". Once the intelligible part of the message has been interpreted through establishing matches with existing cognitive structures, the unmatchable relations may be dealt with through accommodation of the cognitive structure. When the accommodated cognitive structure matches in some sense with the structure of the theory, the theory is said to be understood.

In performing this linking function the analogy may also serve as a motivating device since the student is able to discern that he does have the knowledge to assimilate the new learning material. Perhaps this is what Asimov (1959:535) was referring to when he said that the judicious use of analogies adds to the interest and pleasure of a course.

Analogy and Accommodation

Jenkins (1966) views a concept as a system whose elements are related through a consciously held set of interrelated rules. This view of concepts supplies yet another way in which the use of an analogy in an explanation may aid in the adaptation process. According to Jenkins, if an individual has learned a concept, he has constructed an interrelated set of rules in his cognitive structure which he can apply in attempting to learn a new concept. In learning the new concept, however, the existing set of rules will need some modification. If an analogy can be set up between a familiar concept and the concept to be learned, then each rule of the familiar concept can be transferred to and be tested between or among the corresponding elements of the new concept. If it is applicable, it can be adopted as part of the rule set for the new concept. This process of fitting rules to the elements of the new concept is thought to continue until a point is encountered where a rule of the familiar concept is not applicable

to the corresponding elements of the new concept. In other words, a point of disanalogy is reached and the cognitive structure must accommodate to structure a new rule which will encompass the new relation encountered so a match can be attained between the new concept and the cognitive structure. According to Lazslo (1972) the new rule required is formulated by trial and error learning in which the use of analogy is once again involved. Learning of concepts in Lazslo's model proceeds by the awareness of the problem, formulation of hypotheses, and trial and error activity testing the hypotheses. In this model analogies serve to suggest hypotheses for possible rules to be tested. The hypotheses are generated by the mind system by setting up analogies between the elements of the new concept and different concepts in the cognitive structure. Each hypothesized rule generated from the analogies is tested in the new concept until a satisfactory rule is found or is abstracted from the various analogies. The newly generated rule is then integrated into the set of rules for the new concept. The process of transferring rules from the familiar concept and formulating new rules continues until a satisfactory set of rules is constructed in the cognitive structure to encompass the relations of the elements in the new concept. At this point the concept is said to be understood and the structure of the new interrelated set of rules in the cognitive structure represents a new concept in the mind system. Hence the use of analogy is thought to effect understanding by aiding the adaptation process through pointing out to the learner where accommodation must occur and it is thought to aid in the accommodation process

itself by acting as a device to suggest hypotheses for the formation of new rules.

The use of a well chosen analogy in an explanation can be used to aid the student in transferring rules from a concept with which he is familiar to new concept and discerning points of difference between the familiar and new concepts so the student will be aware of areas where accommodation is necessary. For example, Richmond (1970:68-69) presents an analogy between an amoeba and the mind system in explaining the concepts of assimilation and adaptation in the adaptation process of the mind system to its environment. He points out that the two systems are similar in that the taking in of nutrients and rebuilding them into amoebic substance is comparable to the intellect absorbing experiences and restructuring them to fit them into the cognitive structure. However, a point of disanalogy is reached when it is realized that the nutrient balance between the amoeba and its environment does not change qualitatively during the life of the creature whereas in the case of mental structures, there are changes as the individual gains experiences. Each new experience of the mind system modifies existing mental structures and the cognitive structure becomes more comprehensive in its ability to assimilate and accommodate to new experiences while the ability of the amoeba to assimilate and accommodate to its food remains static throughout its life. In this example, Richmond has transferred the rules governing the familiar behavior of the amoeba to the mind system and has pointed out to the

student an area where the amoebic model requires accommodation to gain an accurate understanding of the mind system.

Analogy and Abstraction

Bruner (1973) has proposed a mechanism of learning in which relational network structures consisting of abstract relations and non-specific elements are incorporated in the cognitive structure. He refers to these structures as "formal coding systems" (Bruner, 1973:220). These formal coding systems or schemata are defined as a set of contingently related, non-specific categories (Bruner, 1973:221). In other words, a formal coding system is like a complex of empty sets between which certain relationships have been established. When content, in terms of concepts, is filled into the empty sets, Bruner claims that the concepts adopt the relationships which existed between the empty sets.

When a formal coding system is initially learned it has content, but by a process of abstraction, generalization of the code takes place, ultimately leaving a network of empty categories tied together by a network of abstract relations. Langer (1953) claims that the mechanism fundamental to the abstraction process is analogy. She maintains that "The great value of analogy is that by it, and it alone, we are led to seeing a 'logical form' in things which may be entirely discrepant as to content" (Langer, 1953:33). It would appear that Langer's statement is an extravagant claim since she neither sub-

stantiates her claim, nor does she indicate the mechanism through which analogies act in the abstraction process. A possible mechanism was suggested, however, by Spearman.

Spearman (1923) has postulated a mechanism wherein analogy functions in the abstraction process. He claims that when man is presented with two or more concepts, there is an immediate evocation of a sense of relation between or among the concepts. Spearman labelled this mechanism the eduction of relations. According to Spearman, the particular relationship which is educed from the many relationships which may obtain is determined by analogy through the process of analogizing. In this process the learner compares the corresponding pairs of elements of the two fields of an analogy and maps the relations of the primary field onto the corresponding pairs of elements in the secondary field. Since the relations between corresponding pairs of elements in the two fields of the analogy are the same, the correct relations are established between the elements of the secondary system and are available for abstraction. Furthermore, since the elements of the two fields of the analogy differ while the relations are the same, the relations become figure and the elements become ground. Hence, the relations stand out from the elements and are more readily available for the abstraction process. This may be the mechanism James (1892) was referring to when he described scientific man as gathering cases from which commonalities could be abstracted.

In summary, Spearman suggests that analogy facilitates the abstraction process by indicating to the learner those particular

relations which are to be educed from the many relations which may obtain between the elements of the secondary field and by making the relations more readily available for the abstraction process.

Analogy and Interpretation

After a structure of relations or formal coding system has been abstracted and incorporated into the cognitive structure, it may be applied to understanding similarly structured new learning materials. When a formal coding system is to be applied to new learning material, the categories of the relational structure must be given content. This process is referred to as interpretation and is effected by filling the empty sets with familiar concepts. An explainer may aid the learner in this process by supplying the learner with the primary field of an analogy. Since the primary field contains familiar elements embedded in the relational structure, the interpretation process is accomplished. The learner is then in a position to employ the primary field as a structural model for understanding the new learning material. The structural model serves as a pattern which may be used to examine the structure of relations in the new learning material through the process of analogizing.

As discussed earlier, the mechanism of matching the appropriate relations may be accomplished through the "eduction of relations" suggested by Spearman. A possible mechanism for correctly matching

the analogates of the primary and secondary fields of an analogy is suggested in Spearman's second principle of cognitive growth, namely, the _eduction of correlates_. According to this principle, if man is presented with a concept and a relation, a second concept or correlate is immediately educed or generated. When a learner is presented with new learning material it may not be evident to him which correlate is to be educed from among the many which may obtain between a given concept and relation. If the explainer presents the learner with the primary field of an analogy, the concepts presented with a given relation in the primary field may indicate to the learner which correlate is to be educed from a concept and the corresponding relation presented in the secondary field. In this way the primary field of an analogy may aid the learner in interpreting the secondary field.

In summary, it has been argued that the use of analogy in explanation aids the learner in the assimilation, accommodation, abstraction and interpretation processes of cognitive growth. Since in these processes analogy in explanation appear to assist the learner in achieving a match between new and existing cognitive structure, it may assist the learner in understanding new learning material. The hypothesis that the use of analogy in verbal explanation may increase understanding of new learning material is put to empirical test in the present study.

RULES FOR CONSTRUCTING ANALOGIES

If analogy is to be used by the teacher in scientific explanations, some guidelines for constructing the primary field of an analogy should be considered for it is the primary field which acts as a projective model for understanding the explanation. Belth (1975) has attempted to supply at least a rudimentary list of properties which should be kept in mind in constructing a primary field for an analogy. While any source can be used as a source of primary fields as long as there are some similar features of relationships with the secondary field, the primary field should have at least the following properties:

1. There must be coherence and consistency within the primary field so that the parts fit together and do not contradict one another.

2. There must be a correspondence between the elements of the primary and secondary fields. That is, the primary field must contain within it correlates of those aspects of the secondary field which are the focus of concern.

3. Since the primary field is constructed for the express purpose of making clear traits, relationships, features, functions, or what is obscure in the secondary field, the primary field must have clarity.

4. The primary field must have at least logical validity, and, where possible, empirical validity.

5. The primary field ought to be derived from some observable realm.

6. The primary field must provide an opportunity to see features, functions, relationships, or ensembles which are not easily seen in the original.

To Belth's list the author would like to add two more properties:

7. The primary field should not be presented at a higher level of semantics nor at a more complex sytactical level than the explanation itself.

8. It should be remembered that the primary field is not meant to be a true copy of the secondary field. However, excessive extraneous material in the primary field may result in confusion of the learner.

The above properties were taken into consideration in constructing the primary fields for the analogies used in the present study.

CLASSIFICATION OF ANALOGIES

Analogies can be classified along five dimensions. The first dimension is dependent on the number of systems employed in the primary field to elucidate the elements and/or relations of the secondary field. If two or more different systems are employed in the primary field to elucidate the elements and/or relations of the secondary field then multiple analogies have been employed. If, on the other hand, one system is employed in the primary field to elucidate the elements and/or relations of the secondary field then a singular analogy has been employed. In the present study singular analogies were employed.

The second dimension is concerned with the nature of the elements in the primary field. The elements of the primary field may be either concrete or conceptual. Concrete elements are actual physical objects whereas conceptual elements are objects that exist solely in the mind system. An analogy which employs concrete objects as the elements of the primary field is known as a concrete analogy. An analogy which employs conceptual objects in the primary field is known as a conceptual analogy. Both types of analogies were used in the present study. The use of the Kinetic Molecular Theory and the use of the letters of the alphabet in Experiments I and III, respectively, constituted conceptual analogies. In the other primary fields of Experiment I and those of Experiment II concrete objects were employed; hence, these analogies constituted concrete analogies.

The third dimension employed to classify analogies deals with the nature of the relationships among the elements of the primary field. The relationships among the elements may exist by virtue of a directly perceived relatedness based on mere correlation—qualitative relations, or they may be more precisely defined in quantitative terms as in a mathematical formula. Hence analogies may be classified as either qualitative or quantitative depending on the relations in the primary field. In the present study only qualitative analogies were investigated.

The fourth dimension employed in the classification of analogies is concerned with the closeness of the matching of elements and relations between the primary and secondary fields. If each element and relation under consideration in the secondary field has a corresponding element and relation in the primary field then the analogy is said to be strong. If only some of the elements and relations of the secondary field have correspondents in the primary field the analogy is said to be weak. In the present study strong analogies were used.

The fifth dimension employed in the classification of analogies in teaching is the mode of presentation of each of the fields of the analogy. Each of the fields may be presented to the learner verbally through speech or the written word, pictorially through the use of pictures and/or diagrams or physically through the use of physical objects. The combinations of these three modes of presentation taken in pairs leads to nine different types of analogy. In the present study verbal (written)--verbal (written) and physical--verbal (written)

analogies were employed. For the purposes of this study, the former is referred to as verbal analogy and the latter is referred to as physical analogy.

In the present study all analogies employed were:

(a) singular since only one primary field system was used to elucidate the elements of the secondary system,

(b) qualitative since the elements of the primary field are related through mere subjectively sensed correlation,

(c) strong since each element and relation under consideration in the secondary field has a corresponding element and relation in the primary field.

Hereinafter, when the word "analogy" is used in reference to the design or results of the present study, singular, qualitative, strong analogy will be implied unless otherwise indicated. Since physical analogy implies the use of concrete objects in the primary field, the use of the terms "physical analogy" implies concrete, singular, qualitative, strong analogy.

DESIGN OF THE STUDY

The present study consisted of three separate experiments which were carried out with secondary school students in the classroom setting. In all experiments one scientific explanation and its associated

criterion test were administered to each subject in written form in a booklet. In two of the experiments (Experiments I and III) the primary field of a verbal analogy also accompanied the scientific explanation in the booklet, except in the case of control group members who received only the scientific explanation and criterion test questions. In the other experiment (Experiment II) the primary field of a physical analogy was demonstrated to experimental subjects and then both experimental and control group subjects were presented with booklets containing the scientific explanation and criterion test.

Since the design of each experiment differed somewhat from the others, a short outline of each is presented in turn.

Experiment I - Verbal Analogies

The sample for Experiment I consisted of 1,258 tenth grade students enrolled in an introductory chemistry course and 814 eighth grade students enrolled in a general science course.

Six different scientific explanations were constructed. Three different physical phenomena were chosen for the content of six scientific explanations: liquid-vapour equilibrium in a closed system, compression of a gas, and diffusion of a mixture of gases. For each phenomenon two explanations based on the Kinetic Molecular Theory were written: one short (approximately 150 words) and one relatively longer (approximately 300 words). For each of the six scientific explanations constructed, the primary field of concrete verbal analogy was written.

Seven treatments were then constructed for each of the six scientific explanations. The first four treatments were constructed by placing the primary field of the analogy in four different positions with respect to one of the scientific explanations. In the first treatment, the primary field of the analogy was placed in a booklet so that it was read by subjects immediately before reading the scientific explanation. The second treatment consisted of placing the primary field of the analogy so that it was read by subjects immediately after the scientific explanation. The third treatment was constructed by presenting to the subject the first paragraph of the explanation immediately followed by the corresponding paragraph of the primary field of the analogy so that it was read by subjects immediately after the scientific explanation. A fourth treatment was constructed by presenting the scientific explanation in the left hand column of a two column page and presenting the primary field of the analogy in the right hand column of the page. A fifth treatment consisted of administering the primary field of the analogy to subjects two days before the scientific explanation was read by the subject. In the sixth treatment the postulates of the Kinetic Molecular Theory were presented to subjects two days before subjects read the scientific explanation. In the seventh treatment (the control group), subjects read only the scientific explanation.

Two types of tests were then constructed for each explanation and its corresponding primary field: an analogy test designed to

measure whether subjects who read the scientific explanation and its corresponding primary field understood the analogy, and a criterion test designed to measure the subjects' comprehension of the scientific explanation. Subjects in first to fifth treatment groups, inclusive, were required to respond to the analogy test and all subjects were required to respond to the criterion test.

Forty-two booklets (six explanations x seven treatments) were then constructed. Booklets for the first to fourth treatments contained the scientific explanation, corresponding primary field, corresponding analogy test and corresponding criterion test. Booklets for the fifth treatment were the same as for those for the first to fourth treatments except they did not contain the primary field of the analogy. Booklets for the sixth and seventh treatments contained only the scientific explanation and the corresponding criterion test. Each of the forty-two booklets was then duplicated so that one set could be issued to males and the other to females. Treatments were administered at random to eighth and tenth grade subjects within classes and the results of the criterion tests were analyzed using twelve 2 x 7 (sex by treatment) fixed effect factorial designs.

Experiment II - Physical Analogies

The sample for Experiment II consisted of one hundred students at the ninth grade level enrolled in general science classes in one school.

The two scientific explanations employed in this experiment consisted of two of the longer explanations written for Experiment I; namely, compression of a gas and diffusion of a mixture of gases. The criterion tests were also identical to those used for these two explanations in Experiment I.

For each explanation, classes were split into experimental subjects and control subjects, by assigning a number to each student and then using a random number table to assign subjects to one of the two groups. The members of the control group were asked to leave the classroom while the researcher demonstrated one primary field of a physical analogy to experimental group members. Each primary field simulated the relations of the corresponding scientific explanation using physical objects. After experimental group members had watched the demonstration, the control group members were called back into the classroom and all students read the corresponding scientific explanation and responded immediately to the corresponding criterion test items. This procedure was repeated for three classes for the compression of a gas topic and two larger classes for the diffusion of a mixture of gases topic. Results were then analyzed using a t-test to test the difference between experimental and control group means for each explanation.

Experiment III - Extended Verbal Analogy

The sample for this experiment consisted of 81 ninth grade students enrolled in a general science course.

For this experiment a scientific explanation (somewhat longer than those employed in Experiments I and II) consisting of 823 words, was written concerning the classification of matter and chemical change. The corresponding primary field of a verbal analogy was then written and a criterion test was constructed and treatments were distributed at random to subjects within classes. Those subjects who received a booklet containing the scientific explanation, primary field of the analogy and the criterion test, were designated as experimental group subjects. Subjects who received the booklet in which only the scientific explanation and criterion test were present constituted the control group. Experimental subjects read the scientific explanation, the primary field of the analogy and then immediately responded to the criterion test items. The control group subjects read only the scientific explanation and then immediately responded to the criterion test. The difference in means of the experimental and control groups was analyzed using a t-test.

HYPOTHESES AND RELATED QUESTIONS

The statement of the problem was analyzed under the following hypotheses.

H_1 There is no significant difference in immediate comprehension between male and female subjects when a concrete verbal or a conceptual verbal analogy is employed in a scientific explanation.

H_2 When a concrete verbal analogy is used in a scientific explanation the sequence in which the primary and secondary fields are read results in differences in immediate comprehension. The hypothesized order of treatment means is:

Pre $<$ Post $\leq$ Within $\leq$ SxS $<$ Advance Analogy.

H_3 When a concrete verbal analogy is used in a scientific explanation, there is no difference in immediate comprehension between sexes for any one of the formats in which the analogy is presented.

H_4 When a concrete verbal analogy is used in a scientific explanation, comprehension of that scientific explanation is greater than when a conceptual verbal analogy is used in the scientific explanation.

H_5 When an analogy is used in a scientific explanation the effect it has on immediate comprehension of the scientific explanation is independent of the topic of the scientific explanation.

H_6 When a verbal analogy is employed in a relatively short scientific explanation, it has little or no effect on increasing the

immediate comprehension of the scientific explanation over that obtained when the scientific explanation is read without an analogy. However, when a verbal analogy is employed in a longer scientific explanation such an increase in immediate comprehension is observed.

H_7 The use of a verbal analogy in a scientific explanation does not increase immediate comprehension of the scientific explanation for subjects in the eighth grade as it does for subjects in the tenth grade.

H_8 The use of a physical analogy in a scientific explanation increases comprehension of the scientific explanation over that obtained when the scientific explanation is presented without a physical analogy. This increase will be greater than that obtained when a concrete verbal analogy is used in the scientific explanation.

The rationale for each of these hypotheses is developed in the review of the literature presented in Chapter II.

These hypotheses are examined under the following research hypotheses, associated questions and by comparison of the results of the three experiments.

Experiment I: Verbal Analogies

Hypothesis

There is no significant difference in criterion score means: (a) between sexes and (b) among treatment formats and (c) there is no significant sex by treatment format interaction effect.

Associated Questions

Is the effect which the use of a verbal analogy in a scientific explanation has on comprehension of the scientific explanation independent of the:

1. type of verbal analogy employed?
2. topic of the scientific explanation?
3. length of the scientific explanation?
4. grade level of the subjects being tested?

Experiment II: Physical Analogies

Hypothesis

There is no significant difference in criterion score means between treatment group (physical analogy) and the control group (scientific explanation only).

Experiment III: Extended Verbal Analogy

Hypothesis

There is no significant difference in criterion score means between the treatment group (verbal analogy) and the control group (scientific explanation only).

DELIMITATIONS OF THE STUDY

The present study employed four different topics selected as being representative of topics included in the chemistry sections in the science curriculum at the eight to tenth grade levels. Since the curriculum guides indicate that these topics are to be taught at a qualitative level, the relations among the elements in the scientific explanations of the present study are qualitative in nature. Therefore, the results of the present study are not generalizable to quantitative relations among the elements of scientific explanations, nor to areas of the science curriculum other than chemistry. They are, however, generalizable to other similar qualitative explanations in the chemistry sections of the junior high school curriculum.

The present study employed only one primary field system for each scientific explanation. Therefore, the results of the present study are not generalizable to multiple analogies.

Since in the present study all the analogies employed were strong analogies, the results of the present study are not generalizable to weak analogies.

Since analogies are frequently employed in science textbooks and in teacher demonstrations, the present study was designed to simulate these two modes of presentation of analogies. Hence, in Experiments I and III the primary and secondary fields of the analogies were presented to subjects in written form to simulate the use of analogies in textbooks (verbal analogies). In Experiment II, the primary field was demonstrated to subjects by the teacher using physical objects and the secondary field was presented to subjects in written form to simulate teacher demonstrations (physical analogies). Since only verbal and physical analogies were used in the present study the results of the study are not generalizable to other modes of presentation of analogies.

The results of the study are limited to the formats in which the primary and secondary fields were presented in the present study.

Since there is some evidence (Lunzer, 1970; Orlando, 1971) which indicates that the understanding of abstract analogies is dependent on the attainment of the proportionality schema which is not evident until the stage of formal operations and it was felt that an understanding of the analogies was necessary for them to be of assistance in increasing comprehension of the scientific explanations, subjects who would normally be at the formal operations stage were used in the present study. Eighth grade subjects (average age:

thirteen years) were used because at this age subjects are just beyond the age at which the onset of formal operations normally occurs but is not equilibrated. On the other hand, tenth grade subjects were used because at this age subjects are near equilibration of the formal operations stage. Since the understanding of the analogy employed in the explanation may be dependent on whether or not the subjects have reached the stage of formal operations and the degree to which this stage is equilibrated, the results of the present study are not generalizable to age groups either younger or older than those employed in the present study.

In the present study comprehension of the scientific passages was measured with a multiple choice test immediately after the subjects had completed the assigned reading task to determine the effect of the use of analogy on immediate comprehension as measured by a multiple choice type of test. Therefore, the results of the present study can not be generalized to comprehension which is measured after an elapse of time between the reading of the scientific explanation and responding to the criterion test.

In summary, the results of the present study are generalizable to the immediate comprehension by students engaged in the study of topics in the chemistry units of the junior secondary science curriculum in which the relations between the elements of the scientific explanations are qualitative and in which the types of analogies employed are singular, qualitative, strong, verbal or physical, and whose primary fields contain concrete or conceptual elements.

LIMITATIONS OF THE STUDY

Schools selected for the present study were schools available to the researcher to carry out the study. While all of the schools approached agreed to participate in the study, they may have been non-representative of the general population by virtue of their extremely co-operative manner. The results of Experiments II and III were obtained within only one school and the researcher was a staff member at that school. Generalization of the results of these two experiments to other schools should be undertaken with caution. While classroom groups within schools were not selected randomly, in every case but one all of the classes at the given grade level participated in the study.

At the suggestion of the principals of the schools involved in Experiment I at the eighth grade level, the administration of advance treatments (Advance Analogies and Advance KMT) was carried out using intact classroom groups. Since the classroom groups employed in these treatments may have been unique in some respect generalization of the results for these two treatments must be done with care.

It was assumed in the present study that the average reading level of the subjects was adequate to follow the syntax of the written material presented to them. If subjects were on the average poor readers or exceptionally good readers then the generalizability of the findings in the present study may be in jeopardy.

In the judgment of four experienced classroom teachers the subject matter of the scientific explanations represented new learning material which might be encountered in a regular classroom situation. If subjects were either completely familiar or completely unfamiliar with the subject matter, the theoretical framework developed for the present study would not be applicable and the results of the experiments would be open to question since the theoretical framework for the present study was based on new learning material as normally encountered in the classroom.

It was further assumed that the primary fields of the analogies were either within the experience of the subjects or could be readily learned and visualized by the subjects. If this assumption was not met, then use of the primary fields could not be of assistance to the learner in understanding the new learning material. Furthermore, it was assumed that the primary fields selected for this study would be more useful to subjects in their attempt to understand the scientific explanations than those which they might spontaneously generate themselves. If subjects were able to generate more helpful primary fields, those supplied would not be used by the learner with the result that the validity of any inferences drawn concerning the learner's use of a supplied analogy would be fallacious in that the learner did not use the analogy presented.

PLAN OF THE REPORT

Chapter I introduced the problem and briefly examined the use of analogy in explanation from the point of view of several cognitive psychologists. It was argued that the use of analogy in explanation serves in a number of different ways to effect understanding of an explanation by aiding in the processes involved in establishing a match between the cognitive structure and the elements and relations of the new learning material. It was hypothesized that since the use of analogy appears to facilitate the matching processes, analogy is a device which can be used in explanation to promote understanding and hence increase comprehension of new learning material.

Rules for generating analogies and the system used to classify analogies in the present study were then presented.

Chapter II presents a more comprehensive and detailed discussion of the use of analogy in explanation to increase comprehension of the explanation. Empirical and theoretical studies related to this use of analogy are reviewed to establish an empirical-theoretical basis for this pedagogical use of analogy and for the hypotheses and parameters of the present study. In the first section, studies are examined which attempt to establish an empirical base for the position that learning is facilitated when the existing cognitive structure can be matched in some manner with the new learning material. The second section reviews empirical studies related to the assumption that analogy is a device which increases comprehension by facilitating

the match between the cognitve structure and new learning material. The third section reviews the role of analogy in new concept formation. The fourth section reviews the research related to the development of analogical reasoning in children. The use of analogy in the different stages of human learning is outlined in the fifth section. In the sixth section, it is argued that the analogical process is a mechanism whereby new concepts may be learned and that this process is one of the mechanisms of the subsumption process of Ausubel's theory of Meaningful Verbal Learning. Ausubel's theory is then employed to generate parameters for the present study. The final section discusses research related to other major parameters of the present research.

Chapter III describes the sample, materials, procedures and statistical design for each of the three experiments in the present study.

Chapter IV is divided into three sections corresponding to the three experiments of the present study. In each section the results of one of the experiments is presented. This is followed by a discussion of the results and their relation to the findings of other researchers and previous pilot studies. The discussions following Experiments II and III also relate the findings of each of these experiments to those of Experiment I.

The final chapter presents a summary of the results of the three experiments, implications of the present study for science teaching and recommendations for further research.

CHAPTER II

REVIEW OF THE LITERATURE

In a review of the literature of analogy one cannot help but be impressed by the great respect philosophers have held for analogy as a learning device on the one hand, and the paucity of research by psychologists and educators on the other. Schon (163:41-44) gives several reasons for this neglect of attention to the role of analogy and metaphor in the formation of concepts. He claims that the rationalist school of thought regards analogy as one of many rhetorical devices whose function is to serve as an ornament to language. Another school takes the position that there are two separate modes of symbolism: one for science and a second for the arts. Analogy and metaphor are clearly placed in the latter and therefore are not to be dealt with in the realm of scientific investigation since they have some sort of mystical powers which are to be used by those not interested in precision of thought. Furthermore, the methodological problems of investigating this inner process are very difficult to overcome. Hence the scientific study of analogical thought processes has been very slow in developing.

In this review of the literature an attempt is made to bring together some of the psychological and philosophical studies which have some bearing on the elucidation of analogical thought processes to lay a foundation for the pedagogical use of analogy.

As pointed out in Chapter I, in the view of cognitive psychologists, learning implies growth of the cognitive structure or mind-system. Growth, in turn, implies construction by the mind-system of new cognitive structures or modification of old ones. The raw materials for this construction process are present apprehensions and cognitive structures already in the mind-system. Construction of new cognitive structures occurs through the processes of assimilation and accommodation. When the assimilation-accommodation process results in a match between new apprehensions and the cognitive structure, the new apprehensions are said to have been understood and new concepts are thought to have been constructed in the mind-system. It follows that any device which aids the assimilation and accommodation processes to achieve this match not only aids the learner in understanding new learning material, it also aids in developing new concepts. The discussion presented in Chapter I indicated that analogy may be such a device. The present chapter examines research related to the assumption that new learning material is comprehended when a match is established between the new learning material and the cognitive structure and the roles that analogy is thought to play in establishing this match.

The research which appears most closely related to an examination of the assumption that new learning material is comprehended when a match is eatablished between the new learning material and the cognitive structure occurs in studies in which transfer of learning paradigm is employed. In these studies experimental subjects are administered an initial learning task with the objective of establish-

ing a certain kind of structure in the cognitive system. The initial learning task is followed by a second task which has an analogous structure. The control group is administered only the second task. The treatments are then followed by a criterion test to measure the difference in achievement between the two groups on the second task. Since the object of the present study is to determine whether understanding of a scientific explanation is enhanced by the presentation of a familiar analogous system through which the elements and relations of the scientific explanation may be ordered, it appears that a survey of transfer-of-learning type of studies is relevant to the present study.

A number of transfer of learning studies were performed during the period 1930-1960 but their popularity in the literature appears to have diminished somewhat since that period. Hence, the literature survey of transfer-of-learning type of studies in the following section is mainly drawn from this time interval.

THE COGNITIVE STRUCTURE AND COMPREHENSION OF NEW LEARNING MATERIAL

Postman (1954), in a series of experiments using geometric figures with college students, attempted to determine the role of explicit training in retention of figural material. He found that subjects given explicit training in the derivation of figural patterns from code models retained the geometric figures better than those who had not

received explicit training. Ausubel (1960) gave college undergraduates an advance organizer two days previous to presenting to them a passage dealing with the metallurgy of carbon steel. He found they were able to learn and retain this unfamiliar material better than students who were presented with the passage alone. In another study using one hundred fifty-five senior undergraduate students, Ausubel and Fitzgerald (1961) found that when new learning material in the form of Buddhist doctrines was presented, students who were knowledgeable in Christianity (the same subject area) did significantly better on a test of Buddhism than those subjects who were not knowledgeable in Christianity. Ausubel and Fitzgerald (1961:268) claimed that the discriminability of the Buddhism learning material varies as a function of the clarity and stability of the established concepts to which it is related. The authors also found that if an advance organizer to furnish ideational anchorage was given two days previous to the presentation of the Buddhism passage, the subjects who were given advance organizers but were not familiar with Christianity score significantly higher on a test of Buddhism than the control group subjects who were not administered the advance organizer.

Other studies (Ausubel and Youssef, 1963 ; Grotelueschen and Sjogren, 1968; Merrill and Stolurow, 1965) in which advance organizers have been employed indicate that comprehension is significantly increased when an advance organizer is given several days before the presentation of the new learning material.

These studies appear to indicate that when the learner has previously established cognitive structures which are similar to those

in the new learning material, learning and retention of the new learning material is enhanced. Since a primary field of an analogy is presumed to be a structure with which the learner is familiar or can easily learn, its use in the presentation of a scientific explanation may result in it acting as a previously established cognitive structure-as an "ideation scaffold" upon which new learning material may be learned and retained.

Studies on rats have indicated that reversal learning is facilitated when the first of two discrimination problems is overlearned (Bruner, 1958). This study seems to indicate that when a pattern of behavior or set of rules for behavior is established in the cognitive structure it can be applied to analogous situations.

Verbal prefamiliarization with the content of films by means of a pretest (Stein, 1952) or by exposure to key words (Weiss and Fine, 1956) also facilitates learning and retention. It appears from these studies that the questions of a pretest or key words become organizing centers in the cognitive structure about which new learning material is learned and retained. If thinking and learning is, as Belth (1975) suggests, based on analogical models of the mind-system, perhaps when an analogy is presented it may become a center about which new learning material can be learned and retained.

Judd (1902) and Henrickson and Schroeder (1941) were able to show that if the general principle of refraction of light was taught previous to trying to hit an underwater target, learning was facilitated.

Erwin (1960) found that if third and fourth grade students were given explicit instruction in the principle that the angle of reflection is equal to the angle of incidence when bouncing metal balls off a barrier to hit a target, they could perform better than subjects not given the principle on the analogous task of reflecting a light beam off a mirror to hit a target. However, this effect does not occur unless subjects are able to perceive the similarity (analogy) between the path of the ball and the path of a beam of light and the governing principle. These studies appear to indicate that scientific principles can act as the primary field of an analogy in understanding and performing novel tasks.

Seward (1966) studied the relationship between previous study in mathematical proportions and ability to solve verbal analogy problems. His sample consisted of nine hundred thirty students in grade eight. He divided the sample into groups on the basis of the number of years the student had studied mathematical proportions and on the basis of I.Q.: high (>124); average (106-124); low (<106). Using analysis of covariance, he found that average students who had studied mathematical proportions in all three grades (five, six and seven), and the average group that had studied proportions in grade seven scored significantly higher on the verbal analogies test than the control group subjects who had not studied proportions in grade five, six, or seven. Furthermore, he found that the study of proportions in all three grades had little effect on low and high I.Q. subjects; however, it made it

possible for the students of average intelligence to perform almost as well as the students of high intelligence on the verbal analogy test. It appears that previous training in mathematical proportions may have some transfer value to the solution of verbal analogies for the average student.

Seward's study appears to indicate that the average group had established in their cognitive structure, as a result of the training, an ability for working with analogical relations which enhanced their ability to perform verbal analogies. In other words a previously established cognitive structure enhanced their ability to comprehend analogously structured new learning material.

A number of other studies indicate that previous learning affects further learning in analogous situations. Some of these are summarized in the following paragraph.

Previous learning in arithmetic (Brownell, 1949; Swenson, 1949; Thiele, 1938) and spelling (Gates, 1935) has been shown to enhance positive transfer. Geometry can be taught to cultivate critical and reflective thinking in other fields (Fawcett, 1935; Ulmer, 1939) and the teaching of genetics can be so organized as to modify superstitious thinking in racial prejudice (Bond, 1940). Liublinskaya (1957), Kendler and Karasik (1958) and Caray and Goss (1957) have shown that the availability of distinctive verbal responses facilitates concept formation and conceptual transfer.

In summary, the above studies indicate that the ability to comprehend and retain new learning materials is somewhat dependent on

previous learning which has a structure similar to that of the new learning material. When the structures are similar, it appears that a match between the cognitive structure and the new learning material is facilitated and understanding and retention is enhanced. When an analogy is used in a scientific explanation, the familiar primary field has within it the structural relationships which match those of the less familiar secondary field. Since the structural relationships are similar, the primary field should facilitate the match between the primary field in the cognitive structure and the new learning material. Hence understanding should be facilitated. In the following section the research related to the ability of an analogy to facilitate understanding is reviewed.

ANALOGY AND UNDERSTANDING OF NEW LEARNING MATERIAL

In the Ausubel and Fitzgerald study described in the previous section, when verbal ability differences were accounted for, it was found that in learning an unfamiliar passage about Buddhism, subjects with a greater knowledge of Christianity scored higher on the Buddhism test than those who had less knowledge of Christianity. If it can be assumed that the subjects were using their knowledge of Christianity as their primary field, it would appear that students who scored higher on the Buddhism test did so because they were using analogy to match the relations of the new learning material to those

relations already in the cognitive structure. Since it was found in their study that those subjects who had a greater knowledge of Christianity did not benefit from the advance organizer as did those who had a lesser knowledge of Christianity, it might be inferred that analogous reasoning in some cases is equal to the use of an advance organizer in achieving comprehension of a written passage.

To determine whether this inference had any substance, Pilot Study IV was designed in which the primary fields for two different scientific explanations (Phase Change and Diffusion as designed for Experiment I) were presented two days previous to administering the corresponding scientific explanations and criterion tests. On both passages the experimental group scored significantly higher on the criterion test than the control groups ($p < .05$). It therefore appeared that presentation of the primary field of an analogy to induce analogous reasoning was worthy of further investigation. Hence, in the present study one of the treatment groups for each scientific explanation in Experiment I was administered the primary field of a concrete verbal analogy two days before the scientific explanation was read. A second treatment group was administered the postulates of the Kinetic Molecular Theory two days before the discourse was read. The postulates were presented to test the claim that the best primary field to use in an explanation is the theory itself (Hesse, 1966). Since Pilot Study IV had indicated that the advance position appeared to be optimal in terms of increasing comprehension, the postulates of the theory were presented in this position to ensure that they would have

optimal conditions for producing an increase in comprehension. While the positioning of these primary fields with respect to the scientific explanation was the same as that used in much of the advance organizer research, the form in which the primary fields were written was not intended to emulate that of an advance organizer.

Nuthall (1968) in a study of teaching strategies conducted with four hundred thirty-two high school students attempted to determine whether different strategies of teaching produced measureable differences in student learning. He employed three different kinds of methods: descriptive moves, comparative moves and instantial moves. Descriptive moves consisted of a description of a characteristic of the concept or a listing of the parts that make up the concept. Comparative moves consisted of a comparison between the concept and some other concept. Instantial moves consisted of identification of an instance or example of the concept. Using these moves, Nuthall made up four teaching strategies:

1. a sequence consisting only of descriptive moves,
2. an alternating sequence of descriptive and instantial moves,
3. an alternating sequence of descriptive and comparative moves, and
4. an alternating sequence of comparative and instantial moves.

The first three represented commonly occurring classroom strategies while the fourth one was included to complete the set.

Nuthall's hypothesis that the inclusion of a comparative move would increase the effectiveness of a strategy was not substantiated.

In fact, for the two different topics taught, the lowest mean scores on an achievement measure were obtained when alternating descriptive and comparative moves were employed. When the two strategies which contained comparative moves were compared to the other strategies, the results indicated that achievement under strategies containing comparative moves was significantly lower for both topics. While the use of an analogy is not specifically mentioned, the description of the comparative move appears to be similar to the use of an analogy. If this assumption is correct, it would appear that the use of an analogy as a teaching strategy does not increase comprehension of the new learning material. However, Nuthall's cell frequency was small and the two topics he used were from social studies as opposed to science which is investigated in the present study.

Dowell (1968) taught the biology concept of function to sixty grade nine high school students. One group was taught the concept using the primary field and the secondary field of visual analogies; the second group was shown the secondary field and a third group was not taught the concept at all. The students in the experimental group, in addition to being shown the primary and secondary fields, were stimulated to formulate their own analogical relationships. All groups were given an analogy test as a pretest and a content test before instruction, immediately after instruction, and three weeks after instruction. The same content test was used in all three cases. On the basis of the analogy test score the sample of sixty students was split into high and low analogy quotient (A.Q.) groups.

The design used for analysis was a 2 x 3 x 2 (sex x treatment x analogy quotient) fixed effect analysis of variance.

The results of Dowell's experiment for both the immediate post test and the retention test administered three weeks after the instruction was given indicated:

1. There is no significant differnece between the group taught by the use of visual analogies, the group taught the same concept without the use of visual analogies, and the group not taught the concept.
2. There is no significant difference on the achievement test means between those students who had high Analogy Quotients and those who had low Analogy Quotients.
3. There is no significant difference on the achievement test means between males and females although the means for females who were taught using visual analogies were numerically higher than the corresponding means for males.
4. There is no significant two-way or three-way interaction effects between or among treatments, analogy quotient and sex.

On the basis of his results, Dowell concluded:

1. The factor of sex does not have any relation to the use or non-use of visual analogies in teaching a selected biological concept.

2. Students taught a biological concept by use of methods which stress analogical relationships in presentation of concept material, and which stimulate students to formulate their own analogical relationships do not comprehend the concept better nor do they retain the material longer than students taught the same concept without the use of analogies or those who were not taught the material at all.
3. A student's ability to discern analogical relations as shown by his score on an analogies test is not related to his ability to learn more effectively when taught by stress on visual analogies in comparison with students taught by the same concept without the use of analogies or those not taught the concept at all.

The results of Dowell's study are somewhat questionable since no significant difference was found between those groups which received eight hours of instruction on the concept and the group which did not receive any instruction on the concept at all. It appears that the subjects in the sample knew the concept before the instructional period, or that the comprehension test instrument did not discriminate well enough between those who knew the concept and those who did not, or the teaching was not effective in terms of the students learning the concept. It would seem reasonable to assume that if no significant differences were obtained between students who were taught the concept

and those who received no instruction, it would be unlikely to find any significant difference between those instructed using visual analogies and those instructed without the use of visual analogies. The results of Dowell's study may have been due to the small cell frequencies employed. Since Dowell had only sixty subjects in a 2 x 3 x 2 analysis of variance design, he had only five subjects per cell. The power of such a design would be low.

In a pilot study (Pilot Study I, see Appendix D) carried out in preparation for the present study, it was observed that females who received instruction using verbal and physical analogies in a scientific explanation had numerically greater means than males under the same instructional conditions. This result, coupled with the same trend in the results of Dowell's study led to the inclusion of sex as a classification factor in Experiment I of the present study. It is hypothesized that there is no significant difference in immediate comprehension between male and female subjects when a verbal analogy is employed in a scientific explanation.

The results of Pilot Study I, which employed the classification of matter as the topic of the scientific explanation, indicated that the use of a verbal analogy in the scientific explanation decreased immediate comprehension over that obtained by the control group which read only the scientific explanation. Furthermore, there was no significant difference between treatment and control group when a physical analogy was employed in the scientific explanation. However, a significant difference was observed between the means of the physical and verbal analogy treatments, favouring physical analogies.

In Pilot Study II (see Appendix D) designed along similar lines to the present study except that a Cloze Test was used as the criterion measure of immediate comprehensions, it was observed that the use of a concrete verbal analogy in a scientific explanation resulted in a significant decrease in immediate comprehension for the "Pre" format with the Phase Change scientific explanation. Also, in Pilot Study III, using multiple choice items for the criterion measure, no significant differences in favour of the control groups were observed between the treatment groups which read the primary and secondary fields and the control groups which read only the secondary field. The results of both of these studies indicated that the use of a concrete verbal analogy in a scientific explanation did not aid immediate comprehension of the scientific explanation.

Dreistadt (1969) attempted to determine the effects of analogies and "incubation time" (i.e. putting the problem temporarily aside) on creative problem solving. Eighty male and female college students between ages twenty and thirty-five served as subjects. Two problems were employed in the experiment: the farm problem and the tree planting problem. Forty of the subjects worked on the farm problem with the instructions to divide the area of the farm into four parts which have the same size and shape. The shape of the farm was a square from which a square one quarter of the area of the larger square had been removed from the lower right hand corner. The other forty subjects were presented with the tree planting problem with the instructions to plant ten trees in five rows with four trees in each row.

For each of two problems, four experimental conditions each employing ten subjects were used: control, pictorial analogies treatment, incubation treatment, and combined pictorial analogies and incubation treatment. The control subjects simply worked on the problems for twenty minutes. The pictorial analogy treatment subjects also worked on the problems for twenty minutes, but there were three pictorial analogies present in the room pertaining to each of the two problems. The incubation treatment subjects worked on the problems for five minutes and then were interrupted for eight minutes during which they were presented with an easy interpolated task of trying to predict which card of a set of playing cards would turn up next. After this they were given seven more minutes to try to solve the problems. The combined pictorial analogies and incubation treatment subjects worked on the problems in exactly the same way as the incubation treatment subjects except that the pictorial analogies were present in the room for the duration of the treatment.

On the farm problem two-way analysis of variance (Pictorial analogies x incubation) indicated that there was a significant interaction effect of pictorial analogies and incubation when problem completion was the criterion. There was no significant incubation effect; however, the pictorial analogies effect was significant but difficult to interpret because of the interaction effect.

For the tree planting problem, in a similar analysis of variance, a pictorial analogy main effect was noted but no incubation

main effect nor interaction effect was noted. The hypothesis that visual pictorial analogies help solve problems appears to have been confirmed. It should be noted that the pictures were analogies in that the three pictures in front of the students while they were working on the problem had similar structures or groupings to the problem and its solution while the content or subject matter of the pictures was different from the problem. Of the twenty-four subjects who solved either of the two problems and had the pictorial analogies in front of them, nine doubted that the pictures helped them and fifteen thought the pictures had helped in finding the solution to the problems.

The research evidence examined concerning the use of analogies to match the new learning material to the existing cognitive structure appears equivocal. Because of the small number of subjects involved in some of the studies, the power of the studies is rather low. The one study by Dowell (1968) using visual analogies in teaching a concept indicates that the presence of such an analogy does not increase comprehension of the concept.

The present study is designed to evaluate whether the use of a verbal or a physical analogy in a scientific explanation increases comprehension of the exaplantion over that obtained when no analogy is used. Furthermore, in the present study care has been taken to insure that cell frequencies are great enough to find a difference in comprehension due to the presence of an analogy if a difference does exist.

ANALOGY AND CONCEPT FORMATION

As outlined in Chapter I cognitive growth implies change in the cognitive structure so that a match can be made between the cognitive structure and the new learning material through the processes of assimilation and accommodation. As a result of these processes, new concepts may be formed and old ones modified to achieve the match.

If the use of analogy is to facilitate the learning of concepts, it must help meet the conditions which enhance concept formation. A review of some of the factors which enhance concept formation and the role analogy is reported to play in meeting these factors follows.

Heidbreder (1947) hypothesized that abstract concepts are more difficult to learn than concrete concepts. In a study using thirty-six university students, she presented the subjects with a series of pictures each of which was named by a nonsense syllable. The same nonsense syllable was associated with all the drawings which represented a certain concept. For example, "relk" was always associated with some type of human face. The three classes of concepts involved were classes of concrete objects (Thing class), nonsense figures (Form class) and numerical relations based on the presence of three, four or six designs (Number class). The concept was said to have been attained when the subject could associate the correct nonsense syllable with

the correct concept on three successive occasions. There were nine different concepts to be learned, through sixteen presentations of nine cards per presentation. The criterion was defined as the presentation number in which the concept was attained. Heidbreder found that concepts involving physical objects (e.g. human faces) were easier to learn than concepts involving forms (e.g. circle drawings) which were, in turn, easier to learn than concepts involving numbers. The order was the order she had hypothesized on a concrete to abstract continuum. It appears that the more a concept is embedded in concrete reality, the easier it is to learn.

Ennis (1965) studied the natural development of three hundred seventy-five grades eight to twelve children to deal with deductive logical forms. He found that children scored significantly higher when concrete familiar terms are employed in problems of class logic than when abstract symbols such as letters are used in the construction of test items.

It would appear on the basis of the research by Heidbreder and Ennis that concrete concepts are more readily manipulated in the cognitive structure than abstract concepts. When an analogy is presented in which concrete objects replace the abstract elements of the new learning material, it is thought that learning is facilitated. Bilsky (1963:73) notes in reference to analogies "When you compare an abstract idea with something that is concrete and familiar to your reader, you enable him to see more clearly what you are talking about, since you present him with a picture." If analogies can perform the

function of rendering abstract material more concrete then they may aid in the comprehension of abstract material Physical models are sometimes used in science explanations to aid in the conceptualization of abstract concepts. Using one hundred and two students in a freshman level general chemistry course designed for science majors, Talley (1973) was able to show that the class of students which manipulated molecular models scored significantly higher on a content test for each of seven instructional units than students who were taught using a didactic teaching method. The seven content tests corresponding to the seven units each consisted of fifty items: fifteen analogy items, ten each at Bloom's knowledge and comprehension levels and five each at the application, analysis and evaluation levels. On the application, analysis and evaluation levels means favoured the experimental group for all units except the first one at the application level. After the third unit of instruction, the F ratios were much larger for each of these cognitive levels. At the knowledge level, the experimental group achieved significantly better on the first two units; however, after the third unit the control group scored significantly better than the experimental group.

At the comprehension level, a significant difference in favour of the experimental group was noted on the eighth unit only. Pre- and post-tests on visualization ability indicated a significant increase for the experimental group but no change for the didactic group.

Talley's study indicates that the utilization of molecular models as an instrument to aid in visualization of chemical concepts may enhance achievement in freshman level college chemistry. Furthermore, it indicates that students with greater experience in visualization score significantly better at the higher cognitive levels of application, analysis and evaluation than students who are taught didactically. On the other hand the students not experienced in visualization tend to perform at essentially the lower levels of knowledge and comprehension and this inexperience seems to retard achievement at higher cognitive levels.

It should be noted that some of the subtests in Talley's study consist of as few as five items. The reliability of these subtests was not reported but may be very low.

To determine whether the use of concrete analogates increase comprehension more than conceptual analogates when employed in a verbal analogy in a scientific explanation, both kinds of analogates are employed in Experiment I. The postulates of the Kinetic Molecular Theory contain conceptual analogates, whereas, the other primary fields contain concrete analogates. It is hypothesized that when concrete verbal analogies are used in a scientific explanation, they will result in a higher level of comprehension of the scientific explanation than when conceptual verbal analogies are employed. In Experiment I of the present study, these two types of analogy were employed in the "advance" format so the results could be compared. To further explore the use of concrete analogates, in Experiment II, concrete physical objects

are employed with two of the scientific explanations from Experiment I to determine whether the use of physical objects which can be seen are more beneficial than verbally presented concrete objects in increasing comprehension of a scientific explanation. It is hypothesized that the use of concrete physical analogies in a scientific explanation will result in a greater increase in immediate comprehension than when a concrete verbal analogy is employed, which, in turn, will result in a greater increase in immediate comprehension than when a conceptual verbal analogy is employed.

Hovland and Weiss (1953) in a study of concept formation using ninety-five college students found that for conjunctive concepts positive examplars increase the rate of learning more than do negative exemplars. A combination of positive and negative exemplars had the greatest effect on increasing the rate of learning. In explaining relations which exist between two situations or objects using an analogy, the primary field of the analogy supplies a positive exemplar of the relationship. Furthermore, when verbal or physical analogies are used, points of disanalogy may become evident. The points of disanalogy specify the scope of the analogy and hence may increase precision of understanding of the field to be conceptualized through limiting the boundaries of the concept and by supplying negative exemplars.

It has been shown that increasing the amount of relevant information increases the difficulty of concept aquisition as does increasing the amount of irrelevant information (Haygood and

Stevenson, 1967; Walker and Bourne, 1961). Because analogy tends to focus on one relationship at a time, the use of analogy should enhance concept formation in terms of limiting both relevant and irrelevant information.

The more salient a concept is, the more readily it is abstracted. Saliency can be effected by varying the background (Turnure and Wallach, 1965). Dreistadt (1969) argues, in Gestalt terms, that in dealing with an analogy the structure emerges as the figure and the subject matter becomes the ground. Thereby the structure becomes salient for purposes of abstraction. In other words, analogy may increase saliency of concepts.

It has been known for some time (Reed , 1946) that instructing the subject to look for common features facilitates concept learning better than merely instructing the subject to learn correct responses. Frase (1970) has classified such cueing strategies under the generic term of "orienting direction." An orienting direction is a verbal stimulus which disposes the learner to respond to certain aspects of new learning material. General instructions to learn (Rothkopf, 1965) and "advance organizers" (Ausubel, 1963) are classes of orienting directions. Dreistadt (1968:114) says that the use of an analogy tells the learner how to think about a problem. According to Schon (1963:62) when a familiar set of relations is transposed to a new situation through the use of analogy, the familiar set of relations becomes a projective model through which the relations of

the new situation are understood. In other words, it appears that Dreistadt and Schon feel that the primary field of an analogy acts as an orienting direction which disposes the learner to focus on the relations of the elements of the new learning material.

Rothkopf (1966) found that when test-like questions were placed in different positions with respect to the material in a written text there was a differential effect on the amount of learning which occurred. If the primary field of an analogy acts as an orienting direction in the same way as test-like questions, it may be that placing the primary field of an analogy in different positions with respect to the new learning material may result in different amounts of learning as well. Rothkopf (1966) found that when two questions were placed after each one thousand words of a reading passage, general comprehension of the passage was significantly greater than that of the control group which read the passage without the test-like questions. However, if the test-like questions were placed before each one thousand word section,general comprehension of the reading passage was not increased. Frase(1968a) found that in some cases the placement of questions before a passage depressed incidental learning well below control group scores. Evidently pre-questions may limit the range of stimuli to which effective learning responses are made. Frase(1968b) also investigated the effect of contiguity of questions to their relevant content. The same questions in groups of 1, 2, 4 and 5 were placed before and after every 10, 20, 40 or 50 sentences,

respectively. When questions occurred before every ten sentences retention of incidental learning decreased substantially. On the other hand, the post question group showed a forty percent increase over the corresponding pre-question group in incidental learning with questions every ten sentences. There was no difference in retention between pre and post-question groups when the questions occurred every fifty sentences.

In order to determine whether or not the primary field of a concrete verbal analogy acts as an orienting direction in the same way as test-like questions, the primary field was placed before, within and after the scientific explanation. Furthermore, to enable the student to read the primary and secondary field in the order of his choice, the primary field was placed beside the secondary field on a divided page. If the primary field acts as an orienting direction in the same way as test-like questions, the mean for the treatment group which reads the primary field after the scientific explanation should be greater than the mean for the treatment group which reads the primary field before the scientific explanation. On the basis of Frase's(1968b)study on contiguity of test questions, the placement of the primary field within the scientific explanation should result in greater comprehension than the "after" treatment. However, since the scientific explanations in the present study were much shorter than the passages used by Frase, it may be that there will be no significant differences between the means of the "within"

and "after" groups. Since in the "beside" treatment the primary field could be read in whatever order the subjects chose, the mean for this group should be greater than or equal to the "after" and "within" groups. Hence the order of the means for these four treatment groups should be before $<$ After $\leq$ Within $\leq$ Beside. In the designations assigned to these formats in Experiment I this order would read Pre $<$ Post $\leq$ Within $\leq$ Beside.

A fifth format used in Experiment I of the present study derives from that suggested by Ausubel (1963). He suggested that an orienting direction in the form of an advance organizer should be presented to the learner several days before the new learning material. Hence the primary field of a verbal analogy was presented to subjects two days before the presentation of the secondary field. Two different kinds of analogy were presented in this "advance" format. One consisted of the primary field of the concrete verbal analogy used in the other four formats. The second consisted of the primary field of a conceptual verbal analogy which was composed of the postulates of the Kinetic Molecular Theory. The first of these two treatment groups is referred to as the Advance Analogy treatment and the second as the Advance KMT treatment. Since the primary field of the Advance Analogy treatment contains concrete analogates whereas the primary field of the advance KMT treatment contains conceptual analogates, it was earlier hypothesized that the Advance Analogy treatment would result in a greater comprehension than the advance KMT treatment.

Pilot Study IV (see Appendix D) indicated that the Advance Analogy treatment significantly increased immediate comprehension over that of the corresponding control group in the case of the Phase Change and Diffusion explanations. On the other hand, the "Post" treatment in Pilot Study III did not result in any such significant difference. Therefore, it is hypothesized that the mean for the advance analogy treatment will be greater than for the "Post" treatment. Hence, the overall order of means for concrete verbal analogies is hypothesized to be Pre < Post ≤ Within ≤ Beside < Advance Analogy. The relative position of the Advance KMT treatment group mean must be determined by the empirical results of Experiment I.

Theoretical considerations discussed later in this chapter indicate that all concrete verbal analogy treatment group means should result in immediate comprehension greater than the corresponding control group means. However, if the "Pre" treatment results in a focus on specific learning rather than general comprehension as Rothkopf and Frase found with pre-questions, it may be that the "Pre" treatment in Experiment I may result in no significant increase in immediate comprehension over that obtained by the corresponding control group.

Carroll (1964:190) in summarizing what is known about concept learning notes that the lesser the information load the subject must carry, the easier is concept formation. The function of an analogy

is to enable the learner to think of some facets of the new learning material in terms of information already possessed. Hence the amount of information needed to process the new learning material is reduced. Perhaps the analogy can function to facilitate concept formation by reducing the information load. As Schon (1963:60) says, "Metaphors are easily carried and can be made to generate indefinite series of expectations which need not be remembered since they can be generated again. They have the condensation essential to instruments of thought."

In summary, the use of analogies in explanation may facilitate concept formation insofar as they can be used to:

1. concretize the concept to be learned by replacing abstract elements with concrete elements,
2. supply positive and negative exemplars,
3. limit the amount of relevant and irrelevant information to be considered at any given time,
4. increase the salience of the concept,
5. instruct the subject to look for the commonality, and
6. reduce the information load.

Since it is thought that the use of an analogy in explanations functions to concretize the concept to be learned, supply positive and negative exemplars, limit the amount of relevant and irrelevant information to be considered, increase the saliency of the concept,

instruct the subject to look for the commonality and reduce the information load, it is hypothesized that the use of analogy in a relatively complex scientific explanation will increase comprehension of the scientific explanation over that obtained when only the scientific explanation is presented to the learner. It would seem plausible that if there is relatively little information in the new learning material the analogy will have little opportunity to perform these functions. However, if the new learning material is more complex, an analogy will have greater opportunity to perform the above functions. It is therefore hypothesized that if an analogy is employed in a relatively short scientific explanation, it will have little or no effect on increasing the comprehension of the scientific explanation; whereas, if an analogy is employed in a longer, more complex scientific explanation, an increase in comprehension of the scientific explanation over that obtained when only the scientific explanation is presented to the learner should be observed. To test this hypothesis in the present study three short scientific explanations were written and three longer scientific explanations were written for Experiment I.

THE DEVELOPMENT OF ANALOGICAL REASONING ABILITY

Lunzer (1970) studied the development of analogical reasoning using one hundred fifty-three boys from age nine to age seventeen. He

hypothesized that children in Piaget's concrete operations level of cognitive development could solve simple analogy problems which required only first-order operations. He assumed that simple analogies of the form Leather:Shoe:Wool: --require no more than concrete reasoning since the child simply "reads off" the relation the first two items and applies it to the third to arrive at the fourth term: "sweater." He then reasoned that such an item could be made more complex by either increasing the degree of abstraction of the analogates or by increasing the complexity of the form of the analogy items.These more complex analogies,Lunzer (1970) hypothesized, would require second order operations and, therefore, would require cognitive operations at the formal operations level. He also wanted to investigate the problem of mathematical proportionality which he felt was related to Piaget's proportionality schema. For these two purposes he constructed a test consisting of two parts. The first part consisted of verbal analogies and the second part consisted of numerical analogies and series completion items.

The section of the test which contained verbal analogy items consisted of four subtests of eight items each. The four subtests differed on the basis of complexity of format. Group A items were simple verbal analogies as in the example above. Lunzer anticipated that these items would be solvable by children in the concrete operational stage. Group B items were the same as Group A items except the analogates were more abstract than in Group A items. Group C items were designed to involve some formal qualities of combinational

reasoning in their solution but the level of abstraction of the analogates was similar to Group A items. Hence these items were considered to be only slightly greater in difficulty than group A items. Group D items were designed at the highest level of complexity so that a second order "monitoring" process was required for their correct solution. This separate process was envisaged as an essential element in formal reasoning. It was, therefore, anticipated that even at the age of eleven few children would be able to solve such items but would begin to discriminate at about the age of twelve or thirteen years.

The results of the study indicated that, across all ages, the sub-tests in order of increasing difficulty were: A, C, B and D as predicted. However, the abstract analogies in Group B with simple format were not significantly different in difficulty from the items of Group D, which had a complex format. Hence, Lunzer concluded that complexity of format was not a factor in determining the difficulty of analogy items. When the results for nine and ten year old subjects were compared on items requiring only concrete operations (Group A) and those requiring formal operations (Group D), it was found that neither type of item could be solved at these age levels. However, at age eleven there was a much greater ability to solve both types of items. Lunzer concluded that neither type of item could be solved at the level of concrete operations and that the simple analogies of Group A also require formal reasoning. This conclusion is pursued further in a study by Orlando (1971) which is reviewed at the end of this review of Lunzer's study.

While the greatest increase in ability to solve analogies of all types occurred between ages ten and eleven, there was a gradual increase in ability thereafter up to age seventeen. It would appear that the ability to understand verbal analogies is associated with the onset of formal operations. However, this ability increases with age until at least the age of seventeen years.

The results of the numerical analogy and series completion type of items indicated a general tendency of the average percentage scores to increase with age with the sharpest rise occurring between nine and eleven years of age. Numerical analogies were found to be more difficult for subjects below eleven years of age than the series completion items. However, while the level of success for numerical analogies was lower at ages nine and ten, thereafter the level of success was consistently higher than it was for series completion. This finding reinforces the conclusions reached with verbal analogies. Lunzer concluded that analogies, whether verbal or numerical, demand a more complex process of reasoning than is available at the concrete operations level. Furthermore, Lunzer found that those items which involved an explicit recognition of proportionality were very difficult for subjects at all age levels and noted the greatest increase in the ability to solve these items between ages nine and eleven. Lunzer concluded that these findings substantiated his hypothesis that mathematical proportionality is based on the proportionality schema which appears in the formal operations stage and is not equilibrated until well into the teenage level.

It should be pointed out that in drawing conclusions about whether or not analogy is related to the stage of formal operations Lunzer assumes his hypothesis. He should have used some of the Piagetian tasks to determine the stage of development of each individual and then administered his test to determine if there is any relationship between the ability to solve the different types of analogy items and the level of cognitive development. Since the stages of cognitive development are not age specific but merely occur in a definite sequence, Lunzer's focus on the age eleven is not justified. This is particularly a concern in Lunzer's study when one considers that there were only six subjects in his age ten group and in only three age groups were there twenty or more subjects. Differences between age groups reported by Lunzer may not be meaningful since only averages are reported and are not subjected to statistical analysis to determine whether the differences in means are significant. Furthermore, while Lunzer compares the results of his sub-tests he does not report reliabilities for them. In view of the fact that the sub-tests consist of eight items, reliability should be a foremost consideration since reliability of tests with few items tends to be low.

With these reservations in mind, the trends in Lunzer's data do indicate that the ability to understand some types of analogy items is related to the child's level of cognitive development.

Orlando (1971) in designing a second study on the development of analogical reasoning, claimed that the simple verbal analogy group

used by Lunzer included items which should have been placed in the category of items requiring formal operations.

Orlando claims that analogy items which can be solved at the level of concrete operations are items in which there is no proportionality between the concepts extracted from the two fields of the analogy. That is, the relationship abstracted from the analogates of the primary field can be transferred directly to the secondary field without any proportional adjustment of the relationship. He calls this type of item concrete verbal analogies. He claims that this type of item is really an example of classification rather than "true" analogy. He defines "true" analogy as an analogy in which there is a proportionate relationship between the two fields of the analogy. This type of analogy he referred to as abstract verbal analogy. He hypothesized that since abstract verbal analogies require a proportionate adjustment in the relationship, the proportionality schema was involved in their correct solution. Since this schema is not available to the child until the stage of formal operations, only children at the formal operations level would be able to solve these items.

Orlando then constructed a test containing twenty items of each type of analogy and administered it to twenty boys at each of the eight age levels from nine to sixteen years.

The results of the study indicated that mean scores on concrete verbal analogies were greater at all ages than for abstract verbal analogies. He concluded that this indicated that there are different

cognitive processes which underlay the two types of analogy items. Nine to ten year old subjects could solve only twenty-two percent of the abstract verbal analogy items while they could solve seventy-six percent of the concrete verbal analogy items. This indicated that at these ages subjects possessed the processes to solve concrete verbal analogy items but were very close to the chance level for abstract verbal analogy items. The first significant difference from the chance level of score on abstract verbal analogy items was observed with the thirteen to fourteen age group. He concluded that this may indicate that formal operations begins at around this age. This was somewhat confirmed by the finding that there was a significant difference between age group eleven to twelve and thirteen to fourteen but no significant difference was noted between any other age groups.

Orlando concluded that the solution of concrete verbal analogies requires only the classification schema evident at the level of concrete operations whereas abstract verbal analogies require the schemas available to the child only at the formal operations stage.

It is interesting to note that even at the ages of thirteen to fourteen the mean score on abstract verbal analogies just reached fifty percent and the fifteen to sixteen age group reached only about sixty-two percent correct. Orlando reports that in another study using college students as subjects with a mean chronological age of twenty years, the mean score for abstract verbal analogy items reached eighty-five percent. The finding that the ability to understand

abstract verbal analogy items continued through the teenage level confirms a similar finding by Lunzer.

In summarizing the work of Lunzer (1970) and Orlando (1971), it appears that the ability to understand abstract verbal analogies problems may be dependent on whether or not the child has achieved the proportionality schema. This is not thought to occur before the onset of formal operations which is not equilibrated until the late teenage years.

The work of Lunzer and Orlando is relevant to the present study insofar as there is an indication that the use of abstract analogies in explanations with students who have not reached the stage of formal operations is not advised since students below the formal operations stage do not have the necessary schema to understand abstract analogies.

In the present study subjects were originally chosen for Experiment I from the tenth grade level (ages: 15-16 years) to insure that the probability was great that subjects had reached the stage of formal operations. Later eighth grade students were chosen to determine whether a different result would be obtained if subjects closer to the onset of formal operations were used. Since the eighth grade child (age approximately 13 years) would not yet have equilibrated the stage of formal operations, it is hypothesized that the presence of an analogy in a scientific explanation would not aid the eighth grade child in comprehension of the scientific explanation as much as it would aid the tenth grade child.

THE USE OF ANALOGY AND THE STAGES OF HUMAN LEARNING

Bruner (1966) demonstrated that human learning appears to progress through three stages: enactive, ikonic and symbolic. First, in the enactive stage man manipulates his environment. Next, in the ikonic stage, he forms images of his manipulations. Then he shorthands the images by representing them with symbols. Templeton (1973) found that the reliance of thinking upon analogy was closely related to the ikonic stage of development. He administered the Photo Analogies Test to one hundred and ten sixth grade students of average intelligence (mean I.Q. - 114) and to forty-nine sixth grade students of high intelligence (mean I.Q. - 143). He labelled the two groups "regulars" and "high achievers," respectively. The subjects were shown each of the ten black and white photographs and were asked to write descriptions of the photographs for people who could not see them. For each figure of speech (analogy, metaphor, simile) used in his description a youngster received one point. The youngsters' Photo Analogies Test scores were then correlated with intelligence, achievement and creative thinking scores. Templeton found that while the high achievers used more figures of speech, the Photo Analogies Test scores for "regular" students correlated positively with measures of intelligence, achievement, and creative thinking. On the other hand "high achievers" Photo Analogies Test scores most often showed either no relationship or, in a number of instances significant negative correlations with measures of intelligence, achievement and creative

thinking. Templeton explained the correlation results on the basis that the high achievers (mean M.A. - 15.5) had mastered the symbolic stage to the extent they were not employing moment-to-moment images. On the other hand, the regular students operating at a mental age of about twelve years had mastered less language and were still using a considerable amount of imagery (i.e. they were still in the ikonic stage). He concluded that students in the ikonic stage relied more heavily upon imagery in their thinking processes than students in the symbolic stage. Templeton (1973:29) contends that when the learner manipulates images in terms of bringing together disparate objects, people, and events he is engaging in a special kind of ikonic thinking: analogizing. In other words, Templeton sees analogizing as the process whereby images are manipulated and transformed. Ausubel (1963) claims that first order concepts are stored in the form of relatively concrete images. He claims that the combination and transformation of these images result in more abstract second-order concepts. If Templeton's interpretation is correct, the combination and transformation of these images is carried out by the process of analogizing.

It appears that the scientist in his development of new scientific explanations may go through the enactive, ikonic, and symbolic stages. In the enactive stage, he gains concrete experiences in the laboratory. In the ikonic stage, he sets up models or analogies to explain his observations. Lee (1969:115) in speaking of the development of scientific theories says, ". . . I will go so far as to say that the abstraction of a general structure follows and is

built upon concrete analogy-making." In summarizing the use of analogies in scientific thinking, Scott (1964:29) says that the scientist has always found it convenient to make use of analogies in his concept formation. Hence, it would appear that analogy operates to abstract concepts from concrete experiences. Finally, in the symbolic stage, the scientist translates his thoughts into a set of verbal or mathematical symbols and uses these in his thinking processes.

It may be the science student on first being confronted with a new scientific explanation, may follow the same sequence of steps in his attempts to conceptualize the new learning material. If this is correct, the student will need an analogy to operate on during the ikonic stage of his thinking process to understand the new concept. The analogy may be supplied by the teacher or text book through the use of an analogy in an explanation.

Moses' (1973) view of the way analogy works in the learning of concepts appears to support the view that the student uses analogy to develop concepts from concrete experiences gained in the enactive stage. He claims that analogizing is the mechanism whereby all first and second order concepts are produced. Moses claims that a child builds up his frame of reference with concrete experiences. These concrete experiences become, through analogy, more abstract first-order concepts. These first order concepts, in turn, become the analogy for the generation of second order concepts. Lee (1969) affirms Moses' position in saying that the human mind is constantly operating with incipient analogies in an attempt to understand its experiences.

It would appear that analogy is used in the thinking process, particularly in the ikonic stage of the development of concepts. If the student is supplied with a concrete model which can be visualized by the student, then the manipulation of this image in relation to the new learning material through the process of analogizing may lead to understanding.

The use of imagery discussed above has implications for the use of analogy with science students. The physiological correlates of visual imagery and alpha brain waves have been studied by Walter (1953). When electroencephalograph recordings are taken over the visual area with the eyes closed and the mind at rest, most people show an alpha rhythm. However, Walter found some people who have no significant alpha rhythms whether or not their eyes are open and their minds at rest. They are people whose thinking processes are conducted almost entirely in terms of visual imagery. The proportion of these "imagery thinking" students is usually higher among science students than among arts students. Since science students (and scientists) are predominantly "imagery thinking" students they would tend to use analogizing (as Templeton defines it) in their thought processes. It may be that if science students think using imagery and analogizing, the use of analogy in explanation may be particularly beneficial to them in understanding new learning material.

THE ANALOGICAL PROCESS AS A MECHANISM IN CONCEPT LEARNING

In Chapter I, it was argued that analogy appears to aid understanding by facilitating the assimilation, accommodation and abstraction processes of cognitive growth. In the present section Schon's model of concept development is presented and the stages involved in Schon's model are equated with the assimilation, accommodation and abstraction processes. Since the stages of Schon's model are equated with these processes and the use of analogy in explanation was seen to facilitate these processes, the use of analogy in explanation is seen to facilitate the stages of Schon's model. Since the outcome of the stages of Schon's model is the formation of a new concept, it follows that the use of an analogy in an explanation facilitates concept formation. These newly formed concepts can, in turn, be applied to the new learning material to obtain a match between the newly formed concepts and the new learning material which results in understanding of the new learning material. Hence, the use of an analogy in an explanation facilitates understanding.

It will be recalled that a concept can be considered to be an inter-related set of rules and the learning of new concepts involves the structuring of a new set of rules through transferring rules from an existing concept and structuring new rules which are, in turn, transferred to the new concept. Since Schon claims his model results in the formation of new concepts, the stages in his model must reflect the stages in the development of a new set of

rules. An analysis of Schon's model indicates that by equating the stages of Schon's model with the stages in the development of a new set of rules, Schon's model does reflect the development of a new concept. Furthermore, it is seen that the stages in Schon's model reflect the stages isolated by Vygotsky (1962) in the development of a new concept.

In the following paragraphs Schon's model of concept development is outlined and the stages are equated to the processes of assimilation, accommodation and abstraction and to the stages of the development of a concept as a set of rules. Then to verify that Schon's model reflects the experimental findings concerning the stages of concept development, the stages of Schon's model are equated with the stages Vygotsky (1962) isolated in the learning of concepts.

Schon (1963) has outlined a process he calls the displacement of concepts which he claims is involved in the evolution of new concepts. Displacement is a process of carrying over an old concept to a new situation. The displacement of concepts is simply another expression for the process of metaphor. Basically, the process involves incorporating within a concept new instances which share to some degree the essence of the concept but are removed from what would ordinarily be called an instance of the concept. In other words, displacement is the extension of a concept to a new kind of instance. However, in the process of so doing, the concept itself may be changed or expanded. In Chapter I this process was analyzed from the point of view of a concept as a set of rules which becomes modified, as required, to encompass a new concept.

The mechanism of Schon's process of metaphor involves five stages: intimation, transposition, interpretation, correction, and spelling out.

Intimation is the stage in which there is a realization that a similarity exists between the existing concept and the new type of instance. This stage is the initiation of the assimilation process and appears similar to the stage James pointed out as gathering together a number of similar cases which appear to have certain commonalities. The cases may be similar in that they have one or more rules in common.

The second stage, transposition, is the making of the metaphor. It is the first shift of the existing concept to the new situation, the first establishment of a symbolic relation between old and new. Since most concepts are complex clusters of sub-concepts, transposition occurs over a period of time as more sub-concepts are shifted to the new situation. In this stage the assimilation process is complete between the commonalities which exist between the two situations. It appears that what Schon refers to as a sub-concept is tantamount to one of the rules of the familiar concept. Hence in this stage one or more of the rules are shifted from the familiar to the unfamiliar concept.

The third stage Schon calls interpretation. This step involves the assignment of a sub-concept to a specific aspect of the new situation. In the interpretation stage the shifted rule becomes consciously assigned to certain elements of the new concept. Spearman's eduction of relations and eduction of correlates operate at this point

to determine the elements of the new concept to which the rule is applicable.

Schon views transposition and interpretation as ordinarily occurring in a single step. An old sub-concept is not transposed to a new situation without transposing it to some specific aspect of the new situation. The two phases are distinguishable as is evidenced by the fact that one is sometimes aware of wondering as to which aspect of the new situation an old sub-concept can be assigned. From a cognitive point of view, the transposition and interpretation stages appear to complete the initial assimilation process.

The fourth stage,correction, refers to the resistance of the already pre-existing structure of the new situation to transposition and interpretation. The old concept cluster and the new concept-structured situation are modified in various ways to match one another so that understanding of the new concept may result. This mutual adaptation may take a variety of forms. For example, aspects of the old concept cluster may be rejected for transposition to the new situation or we may limit the areas of the new situation to which the old theory may be transposed. This process of correction may be a conscious limitation or it may be a series of implicit adjustments. From the viewpoint of the adaptation process, the correction stage is the accommodation of the cognitive structure to the new learning material. This stage appears equivalent to the problem of dealing with the points of disanalogy between the two rule sets. That is, when the two rule systems are not isomorphic, new rules must be

generated and old ones must be modified or deleted. The mechanism whereby this might be accomplished is suggested by Laszlo (1972) in his information-flow model in which he suggested a trial and error matching process using rules from other concepts. As discussed in Chapter I understanding results when a match between an existing concept and a new concept is obtained. It appears that the correction stage results in such a match.

When an attempt is made to explicate the relations between the old concept cluster and the new situation, the metaphor is being spelled out. This stage requires a more explicit attempt at formal theorizing than is common in ordinary practical inquiry. Since transposition is never totally complete, spelling out will remain incomplete. This stage appears to be equivalent to the abstraction stage of cognitive growth since in this stage the form is seen independent of the content. This stage is frequently manifested in the form of a physical, verbal or mathematical model wherein the rules are applied to the elements of a system to verify their goodness-of-fit to the new system. In this stage the form of the new concept is extracted and becomes available for understanding further new learning material.

Schon's theory is that new concepts are formed from elaboration and correction of complex concepts which are displaced from old situations to new ones through the process of metaphor. The old situation becomes symbolic of the new situation. This symbolic relation requires intimation that the new situation has aspects related in the manner of the old. Then the old cluster of concepts

becomes a program for exploration of the new. In this function, the old sets up a set of condensed expectations, a way of naming and fixing the new, a proto-concept, a basis for change (Schon, 1963:61). This explanation of the new in terms of concepts which already exist in the cognitive structure is what Belth (1975) says is thinking. Since it functions through the process of analogizing,he says, "Thinking is analogizing. . . ." (Belth, 1975:5)

In summary, the metaphorical process is a means whereby new concepts may be formed by using old concepts as projective models for new situations. The mechanism of this process involves five steps: intimation, transposition, interpretation, correction, and spelling out. These steps were seen as encompassing those processes operating in the cognitive psychologists model of cognitive growth.

In the case of an analogy (as opposed to a metaphor) in which the secondary field is unfamiliar and the primary field is familiar, there is evidence that the analogy may become transformed into a metaphor. Lemon's (1938) study in which she presented subjects with unfamiliar proverbs and familiar instances of the proverbs tends to support this view. For example, when subjects were asked the nature of the relation between the primary and secondary fields, some of the subjects replied that one <u>is</u> the other (Lemon, 1938:35). In other words, when analogies containing unfamiliar and familiar fields were presented, the relation between the primary field and the secondary field was clearly that of a metaphor. That is, the analogy was transformed into a metaphor.

The mechanism of explanation using analogy may be summarized as follows. The analogy containing an unfamiliar secondary field is presented to the learner. The stated relations act to initiate the first stage of the metaphorical process; namely, intimation. Then the analogy is transformed into a metaphor and the steps of interpretation, correction and spelling-out then follow resulting in the formation of a new concept. This new concept may, in turn, be applied to effect understanding of the new learning material since it enables a match to be established through applying the new concept to the new learning material.

Since it appears that the stages in Schon's model are equivalent to the processes of assimilation, accommodation, and abstraction which are facilitated by the use of an analogy in an explanation and since this use of an analogy initiates the analogical process, it appears that the use of an analogy in explanation facilitates understanding of new learning material. Furthermore, Schon's model also appears to reflect the stages involved in the learning of the set of rules which defines a concept.

Gendlin (1962) has outlined a theory in which metaphor operates in much the same way as in Schon's theory except rather than leading to concept formation his process leads to meaning. According to Gendlin, (1962:6) meaning results when "felt meaning--that prelogical, preconceptual informed stream of feeling that we have every moment--becomes attached to a symbol." (Gendlin, 1962:6). (Gendlin's "felt meaning" seems to have an analogous meaning to Polanyi's (1962) personal

meaning). This coupling of "felt meaning" to symbol is accomplished through the process of metaphor in the following way. In a metaphor a relationship is built between a partly unsymbolized felt meaning and symbols which are the signs of concepts usually meaning something else In other words, a new meaning is created by applying old symbols and their meaning to a new area of experience. The new meaning may have for its symbol the metaphor itself or the metaphor may become interpreted and a new symbol is attached to the felt meaning. For example, a sailor of the sea is known as an argonaut; a sailor of space has become known as an astronaut.

Gendlin's theory indicates that the analogical process not only results in the formation of concepts, it also results in the formation of meaning. This result will be seen to be important in an integration of the analogical process with Ausubel's Theory of meaningful Verbal Learning.

Vygotsky (1962) has isolated a number of stages in the development of new concepts. If Schon's model results in concept formation it should reflect these stages.

Vygotsky traces the development of concepts from "heaps" to "complexes" to "true concepts" through the same syntactical stages as found by Olver and Hornsby (1966). Initially, "word meanings denote nothing more to the child than a vague syncretic conglomeration of individual objects that have somehow or other coalesced into an image in his mind." (Vygotsky, 1962:59-60). This seems to correspond to the intimation stage of the metaphorical process where a number of

instances have been gathered through some similarity but the relationship among them is not clearly defined. The second major step toward "true" concept formation is "thinking in complexes." Here the child groups diverse elements into a complex on the basis of perceptually concrete and factual relationships. Complexes are thus distinguished from "heaps" in that the objects included are united not only by subjective impressions (intimations) but also by "bonds actually existing between these objects" (Vygotsky, 1962:61). They are distinguished from "true concepts" in that an object is included because one of its attributes enters the complex not just as the carrier of that one trait but as an individual, with <u>all</u> its attributes. The single trait is not abstracted by the child from the rest and is not given a special role, as in a concept. In complexes, the hierarchical organization is absent: all attributes are functionally equal (Vygotsky, 1962:64). In terms of Schon's metaphorical process this stage of concept formation appears to be very much the same as the transposition stage in which the metaphor is formed. The exact equivalences have not been explicitly revealed. For example, in the metaphor "man is a wolf," there are implied a number of equivalent relations of which no one stands out above the others--no hierarchy exists at this point. Man and wolf participate in an equal partnership with all their characteristics. It requires the stage of interpretation to reveal the corresponding relationships and which ones take precedence over the others.

Vygotsky's final stage, that of "true" concepts, occurs when the child guides his mental operations "by the use of words as a means of actively centering attention, of abstracting certain traits, synthesizing them, and symbolizing them by a sign." (Vygotsky, 1962:62). This stage of the concept formation appears to involve several stages of the analogical process. In the previous stage complexes were formed where instances of the concept participated with all their attributes as in the metaphor. These complexes are characterized by a set of rules which apply to only a few instances of the total set of instances. By setting up an analogy between the members of two different complexes common relations may be extracted as in the interpretation stage of the analogical process. These relations may in turn be applied to a third complex to determine if they are applicable.

Those that are not must be negated as occurs in the correction stage. Finally, when a rule set is extracted which is applicable to all instances of the concept, the rule set is formalized as in the spelling out process so it can be applied to each instance of the concept. When this is accomplished a match has been made between the new learning material and the set of rules in the cognitive structure. As Orlando (1971) points out, for simple concepts, simple classification techniques may be employed to derive the rule set; whereas, for abstract concepts, the instances of the concept are related to the concept in a proportional way, therefore, the proportionality schema is involved. Since the proportionality schema does not appear

until the onset of formal operations, abstract concept formation is limited to the stage of formal operations.

The last stage of Vygotsky's process of concept formation is accomplished when the concept becomes attached to a symbol to yield meaning. Again this is seen to be accomplished through the metaphorical process as indicated by Gendlin.

Since it appears that Schon's model coupled with Gendlin's reflect the stages of concept formation as outlined by Vygotsky, these models appear to have some validity as a model for the formation of concepts and meaning. Since the use of an analogy in an explanation appears to initiate and facilitate the analogical process, it follows that the use of an analogy in explanation facilitates the formation of concepts and meaning. These new concepts result in understanding of the new learning material. Therefore, the use of an analogy in an explanation should increase understanding of the new learning material.

However, since the analogical process does not explain a number of factors of learning such as maturation, memory, etc., it can hardly be classed as a general theory of learning. Therefore, the process must be integrated into a more encompassing learning theory.

Johnson (1972:27) has pointed out, "The integration of associationist principles for simple learning with cognitive principles for abstract operations offer a possibility of synthesis that is being explored by many contemporary students of thought." Insofar as

analogical reasoning deals mainly with abstract operations, it appears that the cognitive viewpoint will be the most productive course to follow.

Carroll (1964) has pointed out that there is a major difference between concept learning in the classroom and concept learning in the psychological laboratory. Whereas, laboratory studies of concepts typically involve artificial and arbitrary combinations of attributes already familiar to the student, many of those learned in school are legitimately "new." Carroll says,

> New concepts learned in school depend on attributes which themselves represent difficult concepts. In more general terms, concepts learned in school often depend upon a network of related or prerequisite concepts. One cannot very well learn the concept of derivative, in the calculus, until one has mastered a rather elaborate structure or prerequisite concepts (e.g. slope, change of slope, algebraic function, etc.). Further, the attributes on which school-learned concepts depend are frequently verbal, depending on elements of meaning that cannot easily be represented in terms of simple sensory qualities as used in concept formation experiments. (Carroll, 1964:190)

Since Carroll has suggested that most concepts learned in classrooms are embedded in a network of other concepts and are presented through verbal explanation, the present study employs scientific explanations which are presented verbally in written form.

The general theory of cognitive functioning which seems to best lend itself to this kind of school concept learning is Ausubel's theory of Meaningful Verbal Learning (Ausubel, 1963). There are three major criteria which must be met before one can speak about meaningful verbal learning:

1. the material to be learned is potentially meaningful,
2. the learner adopts a learning set to incorporate the new learning material into his cognitive structure in a nonarbitrary, nonverbatim fashion, and
3. the individual has within his cognitive structure appropriate subsumers to which the new learning material can be related.

The first requirement of potentially meaningful material is met if the new learning material has logical meaning and is relatable to a hypothetical cognitive structure which has the necessary ideational background and degree of readiness. The second requirement of potentially meaningful material is met if the new learning material has a meaningful referent in the cognitive structure to which it can be related.

Ausubel's second major criterion, the learning set of the learner, is met if the learner adopts a set to learn the material by relating it to available subsumers in a nonarbitrary manner. In other words, the learner cannot simply memorize the new learning material by rote but must make a conscious effort to relate it to what he already knows.

The third major criterion, the availability of appropriate subsumers, is met if there are subsumers within the cognitive structure which are inclusive, stable and discriminable from the new learning material. If these three criteria are met, then meaningful verbal learning can occur.

Does the use of an analogy in a scientific explanation meet these criteria? Since any scientific explanation being presented must be within the cognitive structure of the explainer, it is relatable to that cognitive structure. Since such explanations have been learned by students of science in the past, they can be related to a cognitive structure which has the ideational background and degree of readiness. Furthermore, it appears the requirement of a meaningful referent is met when an analogy is used in a scientific explanation since the primary field of the analogy supplies a meaningful referent in the cognitive structure to which the new learning material can be related.

Since the use of an analogy implies that the learner is to relate the new learning material to the primary field through relating the two fields, the student adopts a set to learn the material by relating it in a nonarbitrary manner.

The criterion of inclusiveness may be met by selecting a primary field which has within it elements and relations which are in one-to-one correspondence with the elements and relations of the new learning material. If no such inclusive analogy is available then one may be given in advance of the new learning material. Since the primary field of an analogy is chosen from within the experience of the students, it is encoded in the cognitive structure and therefore should meet the requirement of stability of the subsumer. Discriminability, the third requirement of an appropriate subsumer, appears to be well served by the use of an analogy since the primary field is substantivally different from the new learning material as is required by the definition of an analogy.

Hence, it would appear that the use of an analogy in a scientific explanation meets the basic criteria for meaningful verbal learning to occur. Fundamental to Ausubel's theory is the subsumption process. Ausubel claims that at all ages and levels of cognitive development, new learning material is subsumed under more inclusive, established conceptual systems. The subsumption process leads to differentiated cognitive content or a concept. When this differentiated content is associated with a symbol, meaning results.

Basically there are two kinds of subsumption: derivative and correlative. Derivative subsumption occurs when the new learning material relates to the cognitive structure either as a specific example of an established concept or it is supportive or illustrative of a previously learned concept. In either of these two cases the new learning material is directly or self-evidently derivable from or implicit in an already established and more inclusive concept in the cognitive structure. Ausubel says that in derivative subsumption, meaning emerges quickly and effortlessly. However, unless the material is overlearned, it tends to be forgotten rapidly because the meaning of the new material can be adequately represented by the more general and inclusive meaning of the established subsumer. In the second type of subsumptive process, correlative subsumption, the new material is an extension, elaboration, or qualification of previously learned materials. The meaning of the new material in this case is not implicit in, nor can it be adequately represented

by, the subsumers. The rate of forgetting in this case is increased if the subsumers are unstable, unclear or insufficiently relevant, and if the new learning material is lacking in discriminability or is not overlearned. Since the new material is an extension of the subsumer, if one can not recall the material it is lost to memory because it can not be regenerated from the subsumer as in derivative subsumption.

In either case the subsumption process leads to differentiated cognitive content or a concept. When this differentiated cognitive content is associated with a symbol, meaning results. That is, meaning is differentiated cognitive content which results from the subsumption process and is associated with a symbol.

Recall that Gendlin defined meaning in this same relational way. That is, Ausubel sees meaning as a relation between differentiated content and symbol, and Gendlin defines meaning as the relation between "felt meaning" (personal meaning) and a symbol. Ausubel's differentiated content may be equated to Gendlin's "felt meaning" since Ausubel points out that the differentiated content is idiosyncratic because of the differences in cognitive content and previous experience of each individual.

Since it appears that the way in which the authors view meaning appears to be similar, it remains to compare the processes which produce meaning. In Ausubel's theory, meaning is a product of the subsumption process whereas in Gendlin's theory meaning is a

product of a metaphorical process. If the points of view of both Ausubel and Gendlin are to be accepted, it would appear that the metaphorical process is at least one of the processes whereby subsumption occurs. To substantiate this stand, it is observed that Ausubel claims that to obtain maximum effectiveness in the subsumption process, analogies should be used in preparing the cognitive structure to receive new learning material (Ausubel, 1963:214). This claim indicates that Ausubel thinks that analogy functions in the subsumption process. Hence, it appears reasonable to suggest that the analogical process outlined earlier in this chapter may be one of the mechanisms whereby subsumption may occur. If the analogical process is considered to be one of the mechanisms of the subsumptive process then the analogical process may be integrated in to Ausubel's model by equating the stages of the two processes.

Ausubel (1965:71) claims that in most cases of concept formation after early childhood (as in the school classroom) the criterial attributes of concepts are presented to learners in the form of verbal definitions. Ausubel discusses the processes involved in acquisition of concepts through verbal definition:

> Definitional acquisition of a generic meaning involves such <u>active</u> cognitive operations as relating the new concept to relevant established ideas in cognitive structure, apprehending in what ways it is similar to, and different from, related concepts, translating it into a personal frame of reference consonant with the learner's idiosyncratic experience and vocabulary, and often formulating what is for him a completely new idea requiring much reorganization of existing knowledge.
> (Ausubel, 1965:71-72)

An analysis of Ausubel's statement indicates that in the formation of concepts through verbal presentation the following active operations must be present:

1. the new concept must be related to relevant, established ideas in the cognitive structure,
2. the new concept must be translated into a personal frame of reference,
3. the similarities and differences of the new and old concepts must be analyzed, and
4. the new concept must be formulated through reorganization of existing knowledge.

The new concept is related to relevant established ideas in the cognitive structure in the intimation and transposition stages of the analogical process. In the intimation stage a realization occurs that a similarity exists between an existing concept and the new learning material. The use of an analogy in an explanation implies such a similarity. The secondary field becomes related to the primary field which exists in the cognitive structure. Since the primary field of an appropriate analogy contains elements and relations which correspond to the elements and relations of the secondary field and is within the experience of the learner, it meets the requirements of a relevent subsumer in that it is stable, inclusive and discriminable. This relationship between cognitive structure and new learning material becomes more intimate in the transposition stage where the existing sub-concepts become transferred to the new learning material.

The assignment of these sub-concepts to specific aspects of the new learning material follows in the interpretation stage. Hence, it would appear that the use of an analogy in an explanation serves to relate the new learning material to a relevant established subsumer and aids in translating the new learning material into a personal frame of reference since the primary field exists in the cognitive structure of the individual.

The similarities and differences of the new and old concepts are analyzed in the correction stage of the analogical process. In this stage the match between the new learning material and existing concept is analyzed through the process of analogizing. Some of the aspects of the existing concept may be found not relevant to the new learning material and may be rejected or modified in this stage. The function of the use of analogy in an explanation during this stage is to reveal points of similarities and differences through the analysis of points of analogy and disanalogy. This analysis of points of analogy and disanalogy facilitates the analysis of similarities and differences. Furthermore, the use of analogy in an explanation serves to aid in the reorganization of existing knowledge as suggested by Lazslo's information flow model discussed in Chapter I. Hence, it appears that the analysis of similarities and differences between the new learning material and the existing concept and the reorganization of existing knowledge are served by the correction stage of the analogical process.

In summary, it appears the active processes involved in the subsumption process are the same as those involved the analogical process. Therefore, the analogical process is seen as a mechanism of the subsumption process. Hence, it would appear that the analogical process is subsumed by Ausubel's Theory of Meaningful Verbal Learning.

Since the use of analogy in a scientific explanation meets the requirements of meaningful verbal learning and aids in the active stages of the subsumption process which leads to concept formation and meaning, it is hypothesized that the use of an analogy in a scientific explanation facilitates understanding of the scientific explanation and Ausubel's theory may be used to generate parameters for the present study. Ausubel's theory of Meaningful Verbal Learning suggests the following parameters for the present study.

1. Since the new learning material must be relateable to a hypothetical cognitive structure which has the ideational background and degree of readiness, the scientific explanations used in the present study are selected from the existing science curricula of the junior high school program.
2. The primary field which is presented to act as the subsumer must be written to be within the concrete experience of the learner to insure that it can act as a stable, meaningful referent for the new learning material. Hence the primary fields used in the present study were designed using familiar analogates and relations in familiar situations.

3. Since the learner must adopt a learning set to relate the new learning material to the primary field, it was pointed out to subjects that the primary field was presented as a model to enable them to understand the scientific explanations by relating the elements and relations of the primary field to those of the scientific explanations.
4. Since the subsumer must be inclusive, the primary fields of the present study were designed so that the each of the elements and relations in the scientific explanations had corresponding elements and relations in the primary field.
5. To insure that the new learning material was discriminable from the subsumer, the primary fields employed in the present study were chosen from a realm of knowledge substantively different from that involved in the scientific explanations except in the case where the primary field was the postulates of the theory itself.
6. Since the primary fields were designed to facilitate derivative subsumption in the present study and obliterative subsumption occurs rapidly in the case of derivative subsumption, comprehension of the scientific passages was measured immediately after the scientific explanation was read by the subjects.

7. If no satisfactory subsumer is available ,one may be administered several days before the new learning material is encountered. To ensure that the primary fields were available and stable in the cognitive structures of the subjects, the primary fields were also administered two days before the scientific explanations.

In the following section studies are reviewed which suggest additional parameters for the present study.

OTHER PARAMETERS OF THE PRESENT STUDY

Reading of the Passages

Since one of the devices commonly used to aid students in the learning of scientific concepts is the textbook, the present study was designed to simulate textbook usage. Therefore, the scientific explanations were presented to subjects in written form. Since different concepts require explanations of different lengths, several different lengths of explanations were employed.

After a cursory review of the syntactic form used in several science textbooks it appeared that many passages were written in a form which closely corresponds to a hypothetical syllogism. Therefore, it was felt that this form should be used in structuring the scientific explanations for Experiments I and II. Using the same logical form

in all six passages would eliminate the variations in comprehension which might be due to logical form alone. Nevertheless, to insure that any result obtained was not due to logical form, another passage was written in which logical form was not a particular consideration. The structure of this scientific explanation was governed only by the expository requirements of the subject matter.

The readability level of science materials has been a matter of concern with science educators for some time. In a study by Holmquist (1968) designed to develop a readability formula for science, it was concluded that the modified Dale-Chall Formula (Dale and Chall, 1948) gave as good results as a special formula designed specifically for science. Therefore, the modified Dale-Chall Formula for readability was employed in the present study.

In Experiment I of the present study the readability level of the scientific explanations was set at a level higher than the grade level of the subjects while the readability level of the primary field was set near the level of the tenth grade subjects to insure that it was readily understood by tenth grade subjects. This was done to place the burden for understanding the scientific explanation onto the primary field. Of course the readability levels of the scientific explanations were considerably higher than that of an average eighth grade student. This meant that the readability of the scientific explanations was even more difficult for them while the readability of the primary fields were slightly greater than their age level. It therefore would seem plausible that subjects at the eighth grade

level would require the primary field for ordering the secondary field more than tenth grade subjects.

SUMMARY

This chapter began with a review of the research which indicates that the learning of new material is affected by the state of the cognitive structure. Then empirical studies were reviewed in which analogies were used to relate new learning material to the existing cognitive structure to increase understanding of the new learning material.

Since the learning of new material involves the formation of new concepts, research associated with facilitating conditions of concept formation was then reviewed and it was argued that analogies might be useful in attaining these conditions.

A review of two studies relating the development of analogical reasoning to Piaget's stages of cognitive growth indicated analogical reasoning is not fully developed until equilibration of the stage of formal operations.

Schon's model of concept development through the analogical process was outlined and the stages of this process were equated to the stages of concept development. Since Schon's model was found to be inadequate as a general learning theory for classroom learning of concepts, Ausubel's theory of Meaningful Verbal Learning was invoked as general learning theory. It was argued that the use of analogies in scientific explanations appear to satisfy the conditions of meaningful verbal learning and it was argued that Schon's model is encompassed by Ausubel's theory as a mechanism of the subsumption process. Since the subsumption process leads to the learning of new concepts and the use of an analogy in a scientific explanation fulfills the requirements of the subsumption process, it would appear that the use of analogy in a scientific explanation leads to the formation of new concepts which can in turn be used to increase understanding of the scientific explanation. A number of parameters for the present study were then developed from Ausubel's theory and some additional variables involved in the present study were discussed.

CHAPTER III

DESIGN OF THE STUDY

The present study consisted of three separate experiments which were carried out with high school students in the classroom setting. Since each experiment differed from the others, the design of each experiment is presented independently.

It should be recalled that when the word "analogy" is used in reference to the present study, singular, qualitative, strong analogy is implied. Furthermore, since physical analogy implies the use of concrete objects in the primary field, the use of the terms "physical analogy" implies concrete, singular, qualitative, strong analogy.

EXPERIMENT I - VERBAL ANALOGIES

Population and Sample

The population of this experiment from which the sample was drawn was those tenth grade students in Chemistry 10 in the Edmonton Public, Edmonton Separate and St. Albert Separate School systems and those eighth grade students in the Edmonton Public and the Edmonton Separate School systems in the eighth grade core science program.

The sample consisted of 1,258 tenth grade subjects enrolled in Chemistry 10 classes and 814 eighth grade subjects enrolled in the eighth grade core science program. The sample was selected from these grade levels since at these grade levels subjects are expected to be at the level of formal operations. This was considered important since Lunzer (1970) and Orlando (1971) have shown that some types of analogies may not be understood by children who are at the level of concrete operations Since subjects at the eighth grade level are near the age of the onset of formal operations it was anticipated that they would not understand the analogies as well as subjects at the tenth grade level. This same consideration was given to the selection of subjects for Experiments II and III.

Since treatments were distributed to subjects randomly and since there was a broad sampling of schools from within the population the experimental design constituted a "true" experiment (Campbell and Stanley, 1963).

Design

The design of this experiment comprised twelve 2 x 7 (sex x treatment) fixed effect factorial designs.

Development of instruments

Scientific Explanations. Three different physical phenomena chosen from the junior high school chemistry curriculum were used as the topics for six scientific explanations. The three topics were: liquid-vapour equilibrium in a closed system, entitled Phase Change; liquification of a gas by compression, entitled Compression; and separation of two gases by diffusion, entitled Diffusion. These topics were chosen as being representative of topics encountered in the junior high school chemistry curriculum and are frequently explained in chemistry textbooks through the use of concrete verbal analogy (Scott, 1962). Furthermore, as argued in Chapter II, they appear to meet Ausubel's requirement of potentially meaningful material.

For each topic, two scientific explanations based on the Kinetic Molecular Theory were written: one short (approximately one-hundred and fifty words) and one relatively longer (approximately three hundred words). Both lengths of scientific explanations were written in hypothetical syllogistic form: the shorter at argument rank three and the longer at argument rank six. The different lengths of the explanations were employed to determine if there is a differential effect on immediate comprehension when an analogy is employed in short and relatively longer scientific arguments. It was hypothesized that since the information load in a short scientific explanation is light, the primary field of an analogy would not be needed by the learner to order the elements and relations of the

scientific argument. Therefore, the use of an analogy in a short scientific explanation would not increase comprehension of the scientific explanation over that obtained when only the scientific explanation is read. On the other hand, for longer scientific explanations with greater information load, it was hypothesized that the presence of an analogy in the science explanation would increase comprehension over that obtained when only the scientific explanation was read since the primary field would be required by the learner to order the elements and relations of these longer new scientific explanations.

In order to insure that the three scientific explanations at each scientific argument length were comparable in terms of the skills required to read them so that any trends in the results among the different topics could be compared, the following parameters were established:

1. the number of words in each scientific explanation was approximately the same (See Table 1),
2. the number of sentences in each of the scientific explanations was similar,
3. the readability levels of the scientific explanations were similar (See Table 1), and
4. the scientific explanations were written in hypothetical syllogistic form.

Primary fields of verbal analogies. Six primary fields of concrete verbal analogies were then written to correspond to the six scientific explanations. Concrete verbal analogies were employed

TABLE 1

Dale-Chall Readability Levels of Scientific Explanations and Primary Fields

A. Scientific Explanations: Argument Rank Three

Scientific Explanation	Word Count	Number of Sentences	Number of Unfamiliar Words	Average Length Of Sentences	Grade Level
Phase Change	168	7	45	24.0	13-15
Compression	149	7	45	21.3	13-15
Diffusion	167	7	39	23.8	11-12

B. Scientific Explanation: Argument Rank Six

Scientific Explanation	Word Count	Number of Sentences	Number of Unfamiliar Words	Average Length Of Sentences	Grade Level
Phase Change	294	12	76	24.5	11-12
Compression	273	12	84	22.8	13-15
Diffusion	308	12	75	25.6	11-12

C. Primary Field: Argument Rank Three

Primary Field	Word Count	Number of Sentences	Number of Unfamiliar Words	Average Length Of Sentences	Grade Level
Phase Change	131	7	28	18.7	9-10
Compression	124	6	16	20.6	7-8
Diffusion	139	6	28	23.2	9-10

D. Primary Field: Argument Rank Six

Primary Field	Word Count	Number of Sentences	Number of Unfamiliar Words	Average Length Of Sentences	Grade Level
Phase Change	254	13	55	19.5	11-12
Compression	241	13	45	22.8	9-10
Diffusion	274	13	54	21.1	9-10

E. Classification of Matter

	Word Count	Number of Sentences	Number of Unfamiliar Words	Average Length Of Sentences	Grade Level
Scientific Explanation	823	47	204	17.5	11-12
Primary Field	400	23	71	17.4	9-10

in the present experiment because Scott (1964) found that this was the most common type of analogy employed in explanations of chemistry topics in chemistry textbooks. The primary fields used in this experiment were selected from textbooks used in junior high school chemistry programs as aids in explaining the selected topics; however, they were modified somewhat for the present experiment.

In order to insure that the three primary fields at each argument rank level were comparable in terms of skills required to read them so that any trends in the results among the topics could be compared, the following parameters were established:

1. the number of words in each primary field was similar (See Table 1),
2. the number of sentences in each primary field was similar (See Table 1),
3. the primary fields were presented in similar syntactical form,
4. the readability levels of the primary fields were similar (See Table 1),
5. the primary fields were chosen from within the experiential level of junior high school students, and
6. the primary fields were written to form concrete verbal analogies when coupled with the corresponding scientific explanation.

A seventh primary field consisting of the postulates of the Kinetic Molecular Theory was written. Since the theory contains con-

eptual objects, the type of analogy generated when this primary field was coupled with the scientific explanation was a conceptual verbal analogy. This analogy was employed to investigate the ongoing argument that the best primary field for a scientific explanation is the theory itself.

The use of a concrete verbal analogy and a conceptual verbal analogy for each scientific explanation enabled a comparison to be made between the effects which the two types of verbal analogies had on immediate comprehension of the scientific explanation.

The primary fields of the verbal analogies are presented in Appendix A.

Criterion tests. The purpose of the criterion tests was to measure the subjects' comprehension of the content of the scientific explanations.

A criterion test consisting of twenty-five, five-option multiple choice items was constructed for each of the three argument rank six scientific explanations. An effort was made to include some items above category one (knowledge) of the Taxonomy of Educational Objectives: Cognitive Domain (Bloom, 1956). These items were then submitted to three experienced teachers for criticism. After rejection of some items and revision of others, three tests consisting of twenty items each were constructed.

These tests were piloted in Pilot Study III to obtain an item analysis in the following manner. Each subject read the postulates

of the Kinetic Molecular Theory, one of the three scientific explanations, its corresponding primary field and then responded to the corresponding criterion test. A total of one hundred forty-two subjects were employed: forty-seven subjects for Phase Change, forty-four subjects for Compression and fifty-one subjects for Diffusion. On the basis of the items analyses obtained in Pilot Study III, the three tests were revised. Some items were revised, some rejected and a few items were added to make three criterion tests consisting of twenty items each for the argument rank six scientific explanations.

The three argument rank three criterion tests were then composed by selecting fifteen items which were applicable to the argument rank three scientific explanations from each of the argument rank six criterion tests and a sixteenth item which was applicable only to the rank three argument scientific explanation was added to each argument rank three criterion test.

In summary, this process yielded three criterion tests of twenty multiple choice items each having five options for the three argument rank six scientific explanations and three criterion tests of sixteen, five-option multiple choice items each to accompany the three argument rank three scientific explanations. The six criterion tests are presented in Appendix A. Kuder-Richardson Formula 20 reliability coefficients based on the sample employed in Experiment I are presented in Table 2.

Scores on these tests were considered to be measures of comprehension of the scientific discourses. This assumption was

TABLE 2

Kuder-Richardson Formula 20 Reliability Coefficients
For Criterion and Analogy Tests

A. Criterion Tests

Grade	Phase Change		Compression		Diffusion	
	Rank 6	Rank 3	Rank 6	Rank 3	Rank 6	Rank 3
8	0.75 (N = 136)	0.55 (N = 132)	0.67 (N = 135)	0.55 (N = 130)	0.69 (N = 123)	0.55 (N = 128)
10	0.71 (N = 218)	0.62 (N = 204)	0.70 (N = 204)	0.56 (N = 220)	0.77 (N = 212)	0.74 (N = 194)

B. Analogy Tests

Grade	Phase Change		Compression		Diffusion	
	Rank 6	Rank 3	Rank 6	Rank 3	Rank 6	Rank 3
8	0.54 (N = 95)	0.52 (N = 97)	0.55 (N = 101)	0.31 (N = 95)	0.53 (N = 88)	0.39 (N = 93)
Percent of Subjects who Failed Analogy Test*	65.2	42.4	72.4	46.4	73.8	72.0
10	0.59 (N = 144)	0.43 (N = 146)	0.47 (N = 146)	0.36 (N = 151)	0.60 (N = 146)	0.42 (N = 143)
Percent of Subjects who Failed Analogy Test*	22.4	17.1	23.3	11.9	44.5	32.1

*Criterion level for passing set at $x \geq 4$ and $x \geq 6$ for argument rank three and argument rank six tests, respectively

checked in Pilot Study V for the three criterion tests corresponding to the argument rank six scientific explanations. Some randomly selected students read a scientific explanation and then responded to the criterion test while others responded to the criterion test without having read the corresponding scientific explanation. The results obtained were as follows:

	Explanation & Test Means	Test Only Means
Phase Change	13.0 (N - 20)	8.8 (N - 9)
Compression	13.0 (N - 20)	6.8 (N - 19)
Diffusion	12.2 (N - 21)	8.3 (N - 20)

The data confirmed that subjects who read one of the scientific explanations comprehended the scientific explanation significantly better than those who had not read the scientific explanation. The low means of the groups that responded to the test without having read the scientific explanation were interpreted as indicating that the subjects were not very familiar with the content of the scientific explanations employed in the present experiment.

Analogy tests. The purpose of the analogy tests was to measure the subjects' comprehension of the relations which existed between the scientific explanations and their corresponding primary fields. It was reasoned that the comprehension of these relations

would be necessary if the primary field was to be of assistance to subjects in ordering the relations of the scientific explanation.

The analogy test items were originally constructed by the author and then criticized by three experienced teachers. Following revision of the items, the items were employed in Pilot Study III and subjected to items analysis. In Pilot Study III subjects read the postulates of the Kinetic Molecular Theory, the scientific explanation, and the corresponding primary field of the analogy. Then they responded to the analogy test items before responding to the criterion test items. Forty-seven, forty-four and fifty-one tenth grade subjects responded to the Phase Change, Compression, and Diffusion analogy tests, respectively. The items were then revised on the basis on the data from the items analysis in Pilot Study III and a final form of each test was constructed.

The resulting analogy tests which accompanied the argument rank six passages consisted of ten, five-option, multiple choice items. Items one and two were simple analogy items to determine whether subjects could respond correctly to analogy-type items in the format used. Items three to ten were designed to test the students' understanding of the analogous relations and to clarify the understood analogous relations before attempting the criterion tests. The argument rank three analogy test consisted of items one to eight of the argument rank six analogy test.

A copy of each analogy test is presented in Appendix A.

Kuder-Richardson Formula 20 reliability coefficients based on the sample employed in Experiment I are shown in Table 2.

In order to insure that subjects were not responding correctly to the items by word association or by the form of the item, a random sample of subjects was administered the analogy tests corresponding to the argument rank six scientific arguments without having previously been exposed to the scientific explanation or its corresponding primary field and the means were compared with the means obtained by a random sample of subjects who read the scientific explanation and its primary field before responding to the analogy test. The results obtained were:

	Explanation and Primary Field and Test Mean	Test Only Mean
Phase Change	7.3 (N = 12)	4.6 (N = 23)
Compression	6.8 (N = 14)	4.2 (N = 24)
Diffusion	5.7 (N = 13)	3.5 (N = 30)

The results confirmed that those who had read the scientific explanation and primary field scored significantly higher on the analogy test than those who responded to the analogy test only. Furthermore,

when the two sample items were deducted from each individuals total, the means obtained for those subjects who received the analogy test only indicated that the subjects were scoring near the chance level.

Placebo. The placebo entitled "A Fable for Tomorrow" was administered to all students who were not in either the Advance Analogy or Advance KMT treatment groups (see Treatments below). The placebo was extracted from Rachel Carson's book Silent Spring (Carson, 1962:13-14). The content of the placebo was not related to any of the three topics in this experiment.

Treatment groups

For each of the six scientific explanations seven treatment groups were employed. Four treatments were constructed by placing the primary field in a booklet so that the primary field was read by subjects in one of four different sequences with respect to the scientific explanation. The "Pre" treatment group read the primary field immediately before the scientific explanation was read. The "Post" treatment group read the primary field immediately after reading the scientific explanation. The "Within" treatment group read a paragraph of the scientific explanation and then the corresponding paragraph of the primary field throughout the analogy. The "Side x Side" treatment group could read the two fields of the analogy in any order desired by the reader since the corresponding paragraphs of the scientific explanation were placed beside each other on a divided page with the scientific

explanation on the left hand side of the page and the primary field on the right hand side. For the fifth and sixth treatment groups, "Advance Analogy" and "Advance KMT," the primary field of the analogy was not placed in the booklet but was read by subjects two days before reading the scientific explanation. In the "Advance Analogy" treatment the same primary field was employed as in the first four treatments while in the "Advance KMT" treatment the primary field was the postulates of the Kinetic Molecular Theory. The seventh treatment group, the "Control" group, read only the scientific explanation.

Booklets were constructed for each of the six scientific explanations so that subjects in the Pre, Post, Within, and Side x Side treatment groups read the scientific explanation and primary field in the orders outlined above, then responded to the analogy test and then responded to the criterion test. Since in the Advance Analogy treatment, subjects had read the primary field two days previous to receiving the booklet, the primary field was not included in the booklets for this treatment group. Hence the booklets for the Advance Analogy treatment group contained the scientific discourse, the analogy test and the criterion test. The Advance KMT and Control treatment group booklets contained only the scientific explanation and the criterion test since the Advance KMT group members had read the postulates of the Kinetic Molecular Theory two days before receiving the booklet and no analogy test was constructed for this treatment.

In total, forty-two booklets were constructed to correspond to the forty-two cells in the design (three topics x two ranks x seven

treatments). Each booklet was then duplicated so that there was one set for males and one set for females. Booklets for females were marked by stapling a yellow page to the back of the booklet. Each booklet was labelled with a three digit code number to identify it as to topic, argument rank, and treatment group as follows. The first digit indicated the topic of the scientific explanation: Phase Change - 1, Compression - 2, Diffusion - 3. The second digit indicated the argument rank of the scientific explanation: argument rank three - 3, argument rank six - 6. The third digit indicated the treatment: Pre - 1, Post - 2, Within - 3, Side x Side - 4, Advance Analogy - 5, Advance KMT - 6 and Control - 7. For example, booklet 261 contained the topic of Compression (topic 2) at argument rank six with the primary field in the Pre position (treatment group one).

Procedure

The specific details of the procedure employed by the proctor for administering the treatments in the classroom are outlined in Appendix A, however, the general sequence of events is outlined below.

1. Advance Analogies. Two days before the test booklets were to be administered to tenth grade students, a set of primary fields corresponding to each topic and rank (six in total) and a set of six copies of postulates of the Kinetic Molecular Theory were shuffled with enough placebo treatment sheets to make up the number of students in a class. These sheets were then handed out to subjects

in the class in the order they occurred in the pile (random order). This procedure was repeated for every class included in the experiment.

At the eighth grade level four classes were selected at random from the total number of eighth grade classes employed in the experiment and every member of these four classes was administered one of the seven primary fields two days previous to receiving the corresponding booklet. This modification in procedure was necessitated by school administrative problems.

In both of the above cases the analogy sheets were identified by a three-digit treatment code number (as explained above) corresponding to a specific treatment group.

Students at both grade levels were then given four minutes to read the passages and then were asked to write their name and treatment code number on a piece of paper so that the booklet each individual received on the test day would correspond to the passage read.

2. Booklet distribution. Previous to the day of testing identifying pieces of paper were clipped to the corresponding booklet to insure correct distribution of booklets. On the day of testing, those marked booklets were first handed out to those subjects who had received a primary field two days earlier. The subjects who had "placebo"

treatments were distributed booklets at random from the remaining test booklets, the males and females being dealt booklets from separate piles. After a booklet was used it would be placed at the bottom of the pile and would not be redistributed until all other booklets for that sex had been distributed. This was simply a convenient way to distribute the treatments as evenly as possible across the sample. This procedure was modified at the grade 8 level in that in some classes, selected at random, all members of the class were given advanced analogies while other classes had none.

3. Testing. After handing out the test booklets and answer sheets, the required data on the answer sheet were filled in by each student under the guidance of the proctor. Then the instructions on the front page of the booklet were read aloud by the proctor as students followed by reading them from their own booklets.

4. Instructions. All subjects were asked to read the passage (scientific explanation plus primary field, if any) carefully. Those who had analogy tests were asked to complete as many of the items as they could before going on to the criterion test. Those who did not have an analogy test were asked to begin immediately with the criterion test after having read the scientific explanation. It was

pointed out to all students that they could refer back to the passage at any time while they were attempting to respond to any of the test items.

5. Timing. The timing used to give nearly every student enough time to complete all questions was:

    Grade 10: argument rank six passage: 30 minutes
    argument rank three passage: 25 minutes

    Grade 8: argument rank six passage: 40 minutes
    argument rank three passage: 35 minutes

    At the end of each of these times the proctor collected the booklets and answer sheets. Students were required to remain in the classroom for the entire period whether or not they had completed the test.

6. Analysis of Data. The answer sheets were scored electronically by an optical scorer, items analysis and analysis of variance were carried out using computer programs of the Division of Educational Research Services of the University of Alberta.

EXPERIMENT II - PHYSICAL ANALOGIES

Sample

The population for this study consists of students enrolled in grade nine science classes in a secondary school in Vancouver, B.C.

The sample consisted of one hundred students enrolled in five grade nine science classes in the secondary school.

Design

The design of this experiment consisted of an experimental group and a control group which were statistically matched through random selection of subjects into the groups from within classes. A one-tailed t-test was used to compare the criterion test score means of the experimental and control groups. The experiment consisted of employing the Compression and Diffusion argument rank six scientific explanations from Experiment I with their corresponding criterion tests and primary fields of physical analogies were substituted for the primary fields of verbal analogies which were employed in Experiment I.

Development of primary fields

Both analogies employed in this study were physical analogies.

Compression. Ring magnets were embedded in two inch diameter styrofoam balls by cutting the balls in half and cutting out enough of the interior to lay a ring magnet in each ball. The balls were then

glued together again and floated in approximately one inch of water in a glass bottomed tank (ripple tank) which was two inches deep, two feet long and two feet wide. The balls were initially placed as far apart as possible so that the interaction of the magnetic fields was negligible. Then a board shaped like a piston as wide as the ripple tank was brought to the edge of the ripple tank and then slid along the top of the tank. The board contacted the balls as it moved and pushed them toward one end of the ripple tank. As the balls moved closer together they began to attract and accelerate towards each other. The balls eventually were all clustered into one conglomerate. The analogous relations between the balls and molecules, magnetic forces and inter-molecular forces, the clustering of balls to condensation of molecules were orally pointed out to the class by the researcher in an explicit manner. (See scenario in Appendix A). The investigator also demonstrated that if the balls were moving very rapidly past each other in a translational manner the attractive forces would not cause them to cluster. The translational motion was related to temperature of molecules. In this way the concept of critical temperature was explained.

Diffusion. Two plates of glass 8" x 10" were obtained. On three edges (two sides and one end) of one of the glass plates wood strips 1/2" high and 3/4" wide were glued. A hook was screwed into the mid-point of the end strip. A stiff metal rod was attached to the hook. To the other glass plate metal studs slightly shorter than

one-half inch were glued at one-half inch intervals in rows which were one-half inch apart. A space of one and one-half inches with no studs was left at one end and margins of one inch were left along both sides to accommodate the wood strips on the first plate. The rows were staggered so that the studs in the second row were placed in the middle of the spaces of row one but set back one-half inch. This plate was then placed on top of the wood frame with the studs pointing down. Thirty glass beads and thirty lead beads, both one-eighth inch in diameter, were placed at the closed end of the glass box hereinafter referred to as the diffusion demonstration chamber. The diffusion demonstration chamber was then placed on a level over-head projector and the metal rod attached to the hook on the closed end of the diffusion demonstration chamber was attached to a one-half inch radius eccentric on the shaft of a variable speed motor. When the motor was started the diffusion demonstration chamber slid back and forth and the studs contacted the lead and glass beads giving them kinetic energy. The motor was allowed to run for ten seconds or fifty complete cycles (back and forth).

The number of glass and lead beads which left the other end of the diffusion demonstration chamber were recorded for five trials. After each trial the beads which had left the diffusion demonstration chamber were replaced before the subsequent trial was carried out. It was evident that the number of glass beads escaping was greater than the number of lead beads. The results of fifteen trials conducted

previously by the investigator were displayed using an overhead transparency on the overhead projector.

It was explicitly pointed out by the investigator that this demonstration was designed to simulate the diffusion of two gases of different molecular mass through air molecules which were represented by the studs. The demonstrator attempted to insure that all students realized that the lighter glass beads diffused faster than the heavier lead beads even though they both were given the same amount of energy by the oscillating studs. Then the analogous case for the diffusion of two gases was explicitly stated by the investigator.

Procedure

The following procedure was employed for each of the two scientific explanations in this experiment.

1. Random integers were assigned to identify each member of the class. Those with odd numbered integers were asked to leave the classroom for a few minutes. An observer was posted at the door to insure students outside the classroom could neither hear nor see what transpired inside.
2. Subjects remaining in the classroom were presented with one of the primary fields. The instructional procedure was as outlined in the preceding section. A detailed description is presented in Appendix A.

3. After the simulation was completed the odd-numbered students were called back into the room and the booklets containing the scientific explanation and criterion test were distributed. Subjects were instructed to read the scientific explanation and then respond to the criterion test items. They were further told that if they wished to refer to the scientific discourse as they were responding to the criterion test items, they were free to do so. Subjects were given thirty minutes to complete the task.
4. Papers were collected at the end of this time and were scored by the optical scorer.

EXPERIMENT III - EXTENDED VERBAL ANALOGY

Sample

The population for this experiment from which the sample was drawn was grade nine science classes at a secondary school in Vancouver, British Columbia.

The sample consisted of eighty-one subjects enrolled in four grade nine science classes. Two of these classes were taught regularly by the investigator and two classes were taught by another teacher.

Design

The design of this experiment consisted of an experimental group and a control group which were statistically matched by randomly assigning subjects to the experimental and control groups. A one-tailed t-test was used to compare the criterion test score means of the experiment and control groups.

Development of instruments

Scientific Explanation. An eight hundred and twenty-three word scientific explanation was written describing the classification of matter and chemical change. The syntactical form used in this scientific discourse was that determined by the logical requirements of the subject matter.

The topic was chosen because it was part of the regular curriculum at the ninth grade level. Furthermore, the two teachers of the classes involved in the study were able to teach the sequential curriculum up to the point where the next topic to be introduced was the classification of matter and chemical change. This insured that the students had what was considered by curriculum developers to be an adequate background to receive the topic of the present experiment. This preparation of student background was deemed necessary to determine whether the immediate comprehension of an "in-context" scientific explanation was affected by the use of a verbal analogy in the scientific explanation.

A copy of the scientific explanation is presented in Appendix A.

Primary Field. A primary field of a conceptual verbal analogy was written to parallel the structure of the scientific explanation. The analogy compares letters of the alphabet and words with atoms and molecules, respectively. This resulted in a "conceptual" verbal analogy. The analogy is one which is used in science textbooks (Drugge, 1968) and by junior high school teachers. The primary field was placed immediately after the scientific explanation because the results of Experiment I indicated that this position yielded reasonably consistent results in terms of immediate comprehension. A copy of the primary field is presented in Appendix A.

Criterion Test. Twenty, four-option multiple choice were constructed by the researcher. Care was taken to include some items above the knowledge level of Bloom's Taxonomy of Educational Objectives: Cognitive Domain (Bloom, 1956). These items were then submitted to two practising teachers for criticism. After revision of some items and rejection of others the test was employed in Pilot Study I and items analysis was carried out. The items were again revised on the basis of the results of Pilot Study I and the criterion test of fifteen items for the present experiment was constructed. The KR-20 reliability coefficient of the test based on the sample in the present experiment was 0.45. A test-retest reliability coefficient of 0.72 was obtained when an interval of three days was employed. A copy of the criterion test is presented in Appendix A.

Procedure

1. Test booklets which contained the scientific explanation, primary field and criterion test were randomly mixed with an equal number of test booklets which contained only the scientific explanation and the criterion test. The booklets were then distributed to subjects in the order they occurred in the stack of booklets.
2. After completing the required information on the answer sheet, subjects were directed to carefully read the discourse, the analogy (if they had one), and then to respond to the items on the criterion test. Subjects were told that if they wished, they could refer to the discourse or primary field (if one was present) while responding to the criterion test items.
3. Students were informed that the words in the test items were used in the correct scientific sense as they were defined in the scientific explanation.
4. Subjects were given a total of thirty minutes to complete the task. This was found to be ample time.
5. Papers and answer sheets were collected at the end of this time and were optically scored for items analysis and total score.

CHAPTER IV

RESULTS OF THE STUDY

INTRODUCTION

The presentation of the results is divided into three sections corresponding to the three experiments outlined in the previous chapter. A discussion of the results is undertaken after the presentation of results for each experiment. Then an over-all discussion dealing with the major parameters of the study is presented.

Statistical results were computed by the Division of Educational Research Services documented computer programs. In the statistical analyses, a level of significance of 0.05 was adopted for all hypothesis testing. That is, results are said to be statistically significant if the probability of observing such a difference as a result of sampling error is 0.05 or less.

EXPERIMENT I - VERBAL ANALOGIES

Major Hypothesis and Associated Questions

Hypothesis I

There is no significant difference in criterion score means: (a) between sexes, (b) among formats, and (c) there is no significant

sex x format interaction effect.

The format dimension consisted of presentation of the primary field of a verbal analogy in the following positions with respect to the scientific explanation:

1. Immediately before (designated "Pre").
2. Immediately after (designated "Post").
3. Within the scientific explanation so that a paragraph of the scientific explanation was followed by the corresponding paragraph of the primary field (designated "Within").
4. Beside the scientific explanation on a split page so that the primary field was on the right hand side of the scientific explanation and corresponding paragraphs were side by side (designated side x side and abbreviated "SxS").
5. The primary field was read two days before the scientific explanation (designated advance analogy and abbreviated "Adv. Anal.").
6. The postulates of the Kinetic Molecular Theory were read two days before the scientific explanation (designated Advance KMT and abbreviated "Adv. KMT").
7. No primary field was presented. Subjects read only the scientific explanation (designated "Control").

Associated Questions

Is the effect which the use of a verbal analogy in a scientific explanation has on immediate comprehension of the scientific explanation independent of the:

1. type of verbal analogy employed?
2. topic of the scientific explanation?
3. length of the scientific explanation?
4. grade level of the subjects being tested?

RESULTS

Major Hypothesis

Three passages at grade ten level, argument rank three

The results for the three 2 x 7 two-way analysis of variance designs are presented in Tables 3 to 5, inclusive.

Sex main effect. The three tables show that no sex main effects were indicated. In each of the three cases the mean scores of the males were higher than for females. However, this difference was small (0.1 to 0.4).

Format main effect. No significant format main effect was noted in any of the three cases.

1. Phase change: Three of the six means were greater than, two were less than, and one was the same as the mean of the control group.
2. Compression: Two of the six means were greater than the mean of the control group while four means were less.
3. Diffusion: All means were greater than the mean of the control group. The "Post" format mean was greatest at

TABLE 3

Summary of Two-Way Analysis of Variance on Criterion Scores
For Phase Change, Argument Rank Three
Grade Ten: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	.90	1	0.90	0.11	0.74
Treatment	31.64	6	5.27	0.66	0.68
Sex x Treatment	37.75	6	6.29	0.79	0.58
Errors	1561.16	195	8.01		

Homogeneity of Variance Test Chi-Square = 12.4 P = 0.49

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	10.2	11.1	10.8	9.5	9.5	11.3	10.4	10.4
	(15)	(17)	(17)	(17)	(17)	(15)	(17)	
Male	10.7	9.6	11.3	10.2	10.9	10.7	10.2	10.5
	(14)	(11)	(10)	(13)	(15)	(18)	(13)	
Column Means	10.5	10.3	11.1	9.9	10.2	11.0	10.3	

TABLE 4

Summary of Two-Way Analysis of Variance on Criterion Scores
for Compression, Argument Rank Three
Grade Ten: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	11.13	1	11.13	1.73	0.19
Treatment	28.41	6	4.74	0.74	0.62
Sex x Treatment	44.76	6	7.46	1.16	0.33
Errors	1326.20	206	6.43		

Homogeniety of Variance Test Chi-Square = 12.88 P = 0.46

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	9.9	9.8	10.2	9.1	8.8	9.2	8.5	9.4
	(19)	(16)	(19)	(17)	(17)	(17)	(17)	
Male	9.5	10.5	9.7	9.5	9.4	9.2	10.9	9.8
	(14)	(12)	(13)	(12)	(15)	(18)	(14)	
Column Means	9.7	10.1	10.0	9.3	9.1	9.2	9.7	

TABLE 5

Summary of Two-Way Analysis of Variance on Criterion Scores
for Diffusion, Argument Rank Three
Grade Ten: Sex x Treatment

A. Two Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	7.48	1	7.48	0.57	0.45
Treatment	84.74	6	14.12	1.07	0.38
Sex x Treatment	10.13	6	1.69	0.13	0.99
Errors	2405.07	182	13.21		

Homogeniety of Variance Test   Chi-Square = 3.26   P = 0.10

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	10.2	11.3	10.3	10.0	9.7	11.0	9.3	10.2
	(18)	(17)	(18)	(17)	(13)	(17)	(13)	
Male	9.7	11.7	11.0	11.1	10.4	11.3	9.3	10.6
	(11)	(11)	(11)	(11)	(16)	(14)	(9)	
Column Means	9.9	11.5	10.6	10.5	10.0	11.1	9.3	

2.2 points higher than the control mean. When each of the six cells in a given row was compared against the mean of the control group for that row and the results were tallied across the contents, twenty-five cell means were greater than, ten less than, and one was the same as, the corresponding control group mean.

Interaction: No significant sex x format interactions were noted in any of the three cases: Phase Change, Compression, or Diffusion. For none of the three topics (Phase Change, Compression, Diffusion) was the major null hypothesis rejected.

This result is congruent with the hypothesis that the presence of an analogy in a relatively short scientific explanation would have little or no effect on comprehension of the scientific explanation.

Three passages at the grade ten level, argument rank six

The results for these three two-way analysis of variance designs are shown in Tables 6 to 8, inclusive.

Sex main effect: The three tables show that no significant sex main effects were indicated. For the Phase Change and Compression designs, the means were almost identical whereas males scored one point higher than females on the Diffusion passage.

Format main effect

1. Phase Change: A significant format effect was obtained. Neuman-Keuls comparison of means indicated that the "Pre"

TABLE 6

Summary of Two-Way Analysis of Variance on Criterion Scores
for Phase Change, Argument Rank Six
Grade Ten: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	0.56	1	0.56	0.042	.84
Treatment	178.52	6	29.75	2.24	.04
Sex x Treatment	125.58	6	20.93	1.58	.16
Errors	2706.02	204	13.3		

Homogeneity of Variance Test Chi Square = 20.37 P = .086

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	10.4	13.6	13.9	12.0	14.7	14.0	14.1	13.2
	(18)	(15)	(15)	(17)	(16)	(16)	(18)	
Male	11.3	13.2	12.9	15.4	13.2	12.7	13.4	13.1
	(10)	(13)	(12)	(11)	(17)	(21)	(19)	
Column Means	10.8	13.4	13.4	13.7	13.9	13.3	13.7	

TABLE 7

Summary of Two-Way Analysis of Variance on Criterion Scores
for Compression, Argument Rank Six
Grade Ten: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	.07	1	.07	0.006	.94
Treatment	105.86	6	17.64	1.31	.25
Sex x Treatment	35.60	6	5.93	0.44	.85
Errors	2546.01	189	13.47		

Homogeniety of Variance Test   Chi-Square = 16.58   P = 0.22

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv.Anal.	Adv. KMT	Control	Row Means
Female	11.6	11.5	12.1	11.9	13.1	12.1	13.1	12.2
	(15)	(17)	(15)	(16)	(16)	(17)	(16)	
Male	10.5	11.8	11.2	12.7	13.1	13.6	12.8	12.3
	(13)	(12)	(13)	(11)	(18)	(18)	(14)	
Column Means	11.1	11.7	11.6	12.3	13.1	12.9	13.0	

TABLE 8

Summary of Two-Way Analysis of Variance on Criterion Scores
for Diffusion, Argument Rank Six
Grade Ten: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	48.81	1	48.81	2.64	0.11
Treatment	83.39	6	13.90	0.75	0.61
Sex x Treatment	214.09	6	35.68	1.94	0.08
Errors	3669.31	199	18.44		

Homogeneity of Variance Test Chi-Square = 6.91 P = 0.91

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv.Anal.	Adv. KMT	Control	Row Means
Female	12.9	12.0	11.4	8.6	12.9	12.5	11.9	11.7
	(14)	(18)	(14)	(17)	(17)	(17)	(21)	
Male	10.5	12.7	13.7	13.4	13.1	12.8	12.9	12.7
	(15)	(9)	(11)	(14)	(18)	(13)	(15)	
Column Means	11.7	12.3	12.5	11.0	13.0	12.7	12.4	

format mean is significantly-less than the other six means. Comparison of the treatment means indicates that only one cell has a mean greater than the control group whereas five of the means are less. Basically, all means except that of the "Pre" cell are essentially the same.

2. Compression: No significant format effect was indicated. Comparison of treatment means indicates that the means of Advance Analogy, Advance KMT and the control groups are similar. The other four means are 0.7 to 1.9 points less than the control group mean. Again, as in the Phase Change rank six passage, the "Pre" format mean is least at 1.9 points below the control group mean.

3. Diffusion: No significant format effect was indicated. Three of the six treatment means were greater than that of the control group while three cells were less. Differences were very small except the "Pre" and "SxS" format means which were less by 0.7 and 1.4 points, respectively. The mean for males on the "Pre" format was only 10.5.

Interaction: No significant sex x treatment interaction effects were observed in any of the three designs: Phase Change, Compression or Diffusion.

The major null hypothesis was rejected for the Phase Change topic because of the format main effect. The Neuman-Keuls comparison of means test indicated that the format main effect was due to the

mean for the "Pre" format being significantly lower than the other six means. Since the argument rank six scientific explanations are more complex than the less complex argument rank three scientific explanations, it was hypothesized that the presence of a verbal analogy would aid in comprehension of the rank six passages; however, the only significant difference observed indicated a decrease in comprehension when the primary field was placed in the "Pre" format. Since no corresponding significant differences were observed for the Compression or Diffusion passages, or for the Phase Change passage at the argument rank three level, it appears that there may be an interaction between the topic of the scientific explanation and the length of the scientific explanation. This interaction is discussed further under Associated Questions.

Three passages at the grade eight level, argument rank three

The results for the three two-way analysis of variance designs are shown in Tables 9 to 11, inclusive. The low frequencies in each cell should be noted.

Sex main effect: The three tables show that no significant sex main effects were indicated. For the Phase Change passage, the male mean was 0.7 greater than the female mean while the means for Compression and Diffusion favoured females by 0.2 and 0.5, respectively.

Format effect: No significant format main effects were noted for any of the three designs.

TABLE 9

Summary of Two-Way Analysis of Variance on Criterion Scores for Phase Change, Argument Rank Three Grade Eight: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	15.97	1	15.97	1.95	0.17
Treatment	52.91	6	8.82	1.08	0.38
Sex x Treatment	58.08	6	9.68	1.18	0.32
Errors	967.26	118	8.20		

Homogeneity of Variance Test   Chi-Square = 12.3   P = 0.50

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	8.6	6.8	6.6	6.8	8.1	7.1	6.8	7.3
	(10)	(12)	(11)	(11)	(8)	(9)	(12)	
Male	7.6	9.1	8.9	7.8	8.0	8.8	5.8	8.0
	(11)	(9)	(9)	(10)	(5)	(5)	(10)	
Column Means	8.1	8.0	7.7	7.3	8.1	8.0	6.3	

TABLE 10

Summary of Two-Way Analysis of Variance and Criterion Scores
for Compression, Argument Rank Three
Grade Eight: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	0.84	1	0.84	0.11	0.74
Treatment	71.44	6	11.91	1.61	0.15
Sex x Treatment	61.38	6	10.23	1.39	0.23
Errors	856.07	130	7.38		

Homogeniety of Variance Test Chi-Square = 11.0 P = 0.61

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	7.4	5.5	6.3	6.1	8.3	8.3	5.3	6.8
	(10)	(12)	(9)	(10)	(6)	(7)	(10)	
Male	4.8	6.6	6.7	7.4	6.8	7.7	6.0	6.6
	(10)	(8)	(11)	(9)	(10)	(7)	(11)	
Column Means	6.1	6.1	6.5	6.8	7.6	8.0	5.7	

TABLE 11

Summary of Two-Way Analysis of Variance on Criterion Scores
for Diffusion, Argument Rank Three
Grade Eight: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	5.29	1	5.29	0.65	0.42
Treatment	55.31	6	9.22	1.13	0.35
Sex x Treatment	40.64	6	6.77	0.83	0.55
Errors	926.72	144	8.13		

Homogeneity of Variance Test Chi-Square = 14.11 P = 0.37

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	7.0	5.0	6.1	7.1	7.1	6.7	7.6	6.7
	(10)	(10)	(11)	(9)	(7)	(9)	(10)	
Male	5.0	6.3	5.2	5.9	7.9	7.0	6.4	6.2
	(9)	(10)	(9)	(9)	(9)	(7)	(9)	
Column Means	6.0	5.7	5.7	6.5	7.5	6.8	7.0	

1. Phase Change: All six treatment cell means were numerically greater than the control group mean by 1.0 to 1.8 points.
2. Compression: All six treatment cell means were numerically greater than the control group mean by 0.4 to 2.3 points.
3. Diffusion: One treatment cell mean (advanced analogy) was numerically greater than the control group mean while the other five means were less. The "post" and "within" means were less than the control means by 1.3 points.

When the means of each of the six cells in a given row were compared against the mean of the control group for that row, and the results were tallied across the three contents, twenty-three cell means were greater than, twelve were less than and one was the same as the corresponding control group mean.

Interaction: No significant interactions were noted for any of the three topics: Phase Change, Compression or Diffusion.

For none of the three topics was the null hypothesis rejected. This result is congruent with the hypothesis that the presence of an analogy in a relatively short scientific explanation would have little or no effect on immediate comprehension of the scientific explanation.

Three passages at the grade eight level, argument rank six

The results for the three two-way analysis of variance designs are presented in Tables 12 to 14, inclusive. The low frequencies in each cell should be noted.

TABLE 12

Summary of Two-Way Analysis of Variance on Criterion Scores
Phase Change, Argument Rank Six
Grade Eight: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	12.49	1	12.49	0.76	0.38
Treatment	264.26	6	44.04	2.69	0.02
Sex x Treatment	161.89	6	26.98	1.64	0.13
Errors	1995.88	122	16.36		

Homogeneity of Variance Test Chi-Square = 18.6 P = 0.14

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT	Control	Row Means
Female	7.9	6.2	8.3	6.6	7.5	10.2	9.8	8.1
	(10)	(9)	(11)	(12)	(11)	(9)	(13)	
Male	5.3	10.5	7.1	7.0	10.3	9.3	11.3	8.7
	(8)	(10)	(10)	(8)	(6)	(9)	(10)	
Column Means	6.6	8.4	7.7	6.8	8.9	9.8	10.6	

TABLE 13

Summary of Two-Way Analysis of Variance on Criterion Scores
for Compression, Argument Rank Six
Grade Eight: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	11.92	1	11.92	0.98	0.32
Treatment	102.74	6	17.12	1.41	0.21
Sex x Treatment	129.12	6	21.52	1.78	0.11
Errors	1464.64	121	12.10		

Homogeniety of Variance Test Chi-Square = 7.40 P = 0.88

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Ad.Anal.	Adv. KMT	Control	Row Means
Female	6.5	6.3	8.2	6.5	8.3	8.0	7.8	7.4
	(11)	(10)	(10)	(11)	(13)	(10)	(9)	
Male	9.8	6.1	5.0	8.4	8.4	9.8	8.3	8.0
	(10)	(10)	(10)	(8)	(8)	(5)	(10)	
Column Means	8.1	6.2	6.6	7.4	8.3	8.9	8.0	

TABLE 14

Summary of Two-Way Analysis of Variance on Criterion Scores for Diffusion, Argument Rank Six Grade Eight: Sex x Treatment

A. Two-Way Analysis of Variance: Sex x Treatment

Source	SS	DF	MS	F-Ratio	Probability
Sex	1.78	1	1.78	0.12	0.73
Treatment	126.74	6	21.12	1.37	0.23
Sex x Treatment	61.60	6	10.27	0.67	0.68
Errors	1667.26	108	15.44		

Homogeneity of Variance Test Chi-Square = 17.5 P = 0.18

B. Cell Means and Frequencies

	Pre	Post	Within	SxS	Adv.Anal.	Adv.KMT	Control	Row Means
Female	6.0	9.4	8.2	7.6	7.6	9.4	8.8	8.1
	(9)	(10)	(10)	(9)	(8)	(8)	(10)	
Male	7.3	8.0	11.4	7.0	7.8	8.9	8.4	8.4
	(8)	(8)	(8)	(9)	(9)	(8)	(8)	
Column Means	6.6	8.7	9.8	7.3	7.7	9.1	8.6	

<u>Sex main effect</u>: The three tables show that no sex main effects were indicated. In each of the three cases the mean score of the males was numerically greater than the means for females.

<u>Format main effect</u>: Among the three designs only Phase Change had a significant format main effect.

1. Phase Change: The "Pre" and SxS" cell means were significantly lower than the control group mean. All six cell means were numerically less than the control group mean.
2. Compression: Of the six experimental group means, three were numerically greater than the control group mean while three were less. Of the two formats which were significantly lower in Phase Change, "Pre" is numerically greater than the control group mean by 0.1 while "SxS" is numerically smaller by 0.6 points.
3. Diffusion: Of the six experimental group means, three were numerically greater than the control group mean while three were numerically less. Of the two formats which were significantly less in Phase Change, "Pre" and "SxS" are numerically smaller than the control group mean by 2.0 and 1.3 points, respectively.

<u>Interaction</u>: No significant interactions were noted for any of the three topics.

When each of the six cells in a given row was compared against the mean of the control group for that row and the results were tallied

across the three contents, twelve cell means were greater than and twenty-four less than corresponding control group mean.

The major null hypothesis was rejected for the Phase Change topic because of the format main effect. The Neuman-Keuls comparison of means test indicated that the format main effect was due to the means for the "Pre" and "SxS" formats being significantly less than the control group. Since the argument rank six scientific explanations are more complex than the less complex argument rank three scientific explanations, it was hypothesized that the presence of a verbal analogy would aid in immediate comprehension of the rank six passages; however, the only significant differences observed indicated a decrease in immediate comprehension when the primary field was placed in the "Pre" and "SxS" formats. Since no corresponding significant differences were observed for the Compression or Diffusion passages or for the Phase Change passage at the argument rank three level, it appears that there may be an interaction between the topic of the scientific explanation and the length of the scientific explanation. This interaction is discussed further under Discussion of Results.

Order of Treatment Group Means: The treatment group means were placed in rank order, from least to greatest, and assigned values one to six, respectively. Ties were averaged. The values were then summed across the twelve designs for each format. The rank order and values were as follows:

Format	Pre	Post	Within	SxS	Adv. Anal.	Adv. KMT
Total	29	40	41	33	52.2	56.5
Rank Order	1	3	4	2	5	6

Similar rankings were obtained when the same computation was carried out keeping rank six and rank three agruments separate.

It may be noted that when the treatment means are ranked, the "Pre" and "SxS" formats appear to form a pair, the "Post" and "Within" another pair then the "Adv. Anal." and "Adv. KMT" a third pair. The "Pre" and "SxS" being the least helpful and "Adv. Anal." and "Adv. KMT" being the most helpful in terms of immediate comprehension.

Summary of Results of Major Hypothesis of Experiment I

Sex main effect: In none of the twelve cases (three contents x two argument ranks x two grades) was a significant sex main effect noted. In nine of the twelve cases, the means for males were numerically greater than the means for females. In no case, however, was this difference of means greater than 1.0.

Format main effect: In only two of the twelve cases was there a format main effect. These both occurred for the Phase Change passage at the argument rank six level (at both grade levels). Further analyses using the Newman-Keuls Test for differences among means indicated that in both cases the "Pre" format cell means were significantly lower than the control group means and at the eighth grade

level the "SxS" treatment mean for Phase Change was also significantly lower than the control group mean. Analysis of the patterns of the means indicates that when analogies are presented concurrently with the scientific explanation, means tend to be depressed. Analysis of means of the "Pre", "Post", "Within" and SxS" cells versus their corresponding control group means indicated that, at argument rank six, nineteen means were numerically less while only four means were greater, and one was the same as the corresponding control means whereas at argument rank three, only six means were less while sixteen means were greater, and two were the same. On the other hand, analysis of means of the "Advanced Analogy" and "Advanced KMT" cells versus their corresponding control group means indicated that, at argument rank six, five means were numerically less while seven were numerically greater whereas at argument rank three, four means were numerically less while eight were numerically greater.

In summary, there was a numerical trend which indicated that, for argument rank six passages, analogies presented concurrently with the discourses tend to depress comprehension while those presented in the advanced position tend to favour increased comprehension. For argument rank three passages, analogies presented concurrently with the discourses and those presented in the advanced position tend to favour increased comprehension. It must be stressed that this summary is based on simple numerical and not statistical differences; however, the above mentioned pattern does seem to exist even though it is a tenuous one.

Sex x format interaction: In none of twelve cases (two grades x two argument ranks x three contents) was a significant interaction effect noted.

It was concluded on the basis of the above results that the major null hypothesis was not rejected except for the argument rank six Phase Change scientific explanation at both grade levels.

Associated Questions

1. Is the effect which the use of a verbal analogy has on immediate comprehension of the scientific explanation independent of the type of verbal analogy employed?

It was hypothesized that when a primary field containing concrete verbal analogates were employed in a scientific explanation, immediate comprehension would be greater than that obtained when a conceptual verbal analogy was employed. This hypothesis was derived from the work of Heidbreder (1947) and Ennis (1965) who found that it was more difficult to manipulate concrete objects than abstract objects in the thinking process. This hypothesis was tested in the present experiment by employing both concrete and conceptual analogies in the advance format. Since no significant differences were observed between the means of the two types of analogy in any of the twelve cases tested, it would appear that the effect which the use of a verbal analogy has on immediate comprehension is independent of the type of verbal analogy employed.

2. Is the effect which the use of a verbal analogy has on immediate comprehension of the scientific explanation independent of the topic of the scientific explanation?

The only significant differences observed between control group means and treatment group means were associated with the Phase Change topic, argument rank six. At both the eighth and tenth grade levels the means for the "Pre" format treatment group were significantly lower than the corresponding control group means and at the eighth grade level the "SxS" format treatment group mean was significantly lower than the control group mean. Since no corresponding significant differences were observed for the Compression and Diffusion topics, it would appear that the effect which the use of a verbal analogy in a scientific explanation has on immediate comprehension of a scientific explanation is not independent of the topic of the scientific explanation.

Since evaporation and condensation are often dealt with in science programs during the elementary grades, it may be that the Phase Change topic was relatively familiar to the subjects of the present experiment. Hence, it may be that when the primary field of a concrete verbal analogy is read previous to a relatively familiar rank six scientific explanation, immediate comprehension of the scientific explanation is lower than when the scientific

explanation is read without the primary field of the scientific explanation. However, it should be noted that the "Pre" format mean was less than the corresponding control group mean for five of the six argument rank six passages.

3. Is the effect which the use of a verbal analogy has on immediate comprehension of the scientific explanation independent of the length of the discourse?

It was argued that the use of an analogy in a relatively short scientific explanation would have little effect on immediate comprehension of the short scientific explanation since the complexity of the argument is not great enough to require an external model to order the elements and relations of the explanation. This argument was substantiated by the results of the present experiment since no significant differences were observed between treatment groups which were administered analogies and their corresponding control groups which were administered argument rank three scientific explanations only.

It was also argued that the use of a verbal analogy in longer, more complex argument rank six scientific explanations would increase comprehension of the scientific explanation over that obtained when only the longer scientific explanation was presented to the learner. This argument was not supported by the results of the present experiment.

In fact, in three of the thirty-six treatment groups for which verbal analogies were employed in argument rank six scientific explanations, immediate comprehension was significantly less than for the corresponding control groups. No significant differences were observed between treatment and control groups for the other thirty-three treatment groups. Furthermore, a numerical trend was apparent in the data when the criterion score means for analogies containing argument rank three scientific explanations and analogies containing argument rank six scientific explanations were compared with their respective control group criterion score means. In the case of analogies in which argument rank three scientific explanations were employed, the criterion score means appeared to favour increased comprehension over that obtained by the respective control groups. However, in the case of analogies in which argument rank six scientific explanations were employed, the criterion score means for treatment groups in which the primary fields of the analogy were read at the same sitting as the scientific explanation appeared to favour the respective control groups while criterion score means for treatment groups which were administered the primary field two days previous to reading the scientific explanation indicated that the primary fields had little or no effect on the comprehension of the scientific discourse. The results of the present study indicate that the presence of an analogy in a scientific explanation tends to increase comprehension of shorter scientific explanations and decrease comprehension of longer scientific explanations when the primary field of the analogy is administered at the same time as the scientific explanation.

Since comprehension of the longer scientific arguments appeared to be decreased when the primary field of the analogy was administered at the same time as the scientific explanation, it appears that the presence of the primary field increases the information load rather than decreasing it.

The results of the present experiment indicated that immediate comprehension was significantly decreased in the case of the Phase Change argument rank six scientific explanation for the "Pre" format at both grade levels and for the "SxS" format at the eighth grade level. Since the significant decrease in comprehension occurred for the Phase Change argument rank six scientific explanation but no comparable significant decrease in comprehension was observed for the Phase Change argument rank three scientific explanation, it appears that the effect which the use of a verbal analogy in a scientific explanation has on immediate comprehension of the scientific explanation is not independent of the length of the scientific explanation for the Phase change topic.

It would appear that the lack of independence of the length of the scientific explanation may be a function of the students background knowledge of the topic. An examination of the subjects' background revealed that they might be more familiar with the concepts involved in the Phase Change passage than with those included in the Compression or Diffusion passages. It appears that the presence of the primary field in the "Pre" format at both grade levels and the "SxS" format at the eighth grade level resulted in decreased comprehension

of the topic which the subjects would ordinarily comprehend best. This may indicate that when the primary field was placed in these formats for the more complex arguments, the presence of the primary field resulted in confusion on the part of subjects being tested. Since, in the case of the "Pre" format, subjects would encounter the primary field before being aware of the subject matter it is related to, the primary field may result in confusing the subjects rather than aiding them since the topic would ordinarily be relatively well understood without the presence of the primary field. If this supposition is correct, it would appear that for relatively complex scientific explanations with which the subject is already somewhat familiar, the placement of the primary field in the "Pre" or "SxS" format will hinder immediate comprehension of the subject matter.

4. Is the effect which the use of a verbal analogy has on immediate comprehension of the scientific explanation independent on the grade level of the subject being tested?

At both grade levels the Criterion Score means of the "Pre" format for the Phase Change scientific explanation (argument rank six) were significantly less than the corresponding control group criterion score means and at the eighth grade the criterion score of "SxS" format for the same scientific explanation was significantly lower than the

corresponding control group criterion score mean. No other significant differences were observed between treatment and control group means at either grade level. Since the pattern of significant differences between treatment and control groups were identical except for the "SxS" format mean at the eighth grade level, it appears that the effect which a verbal analogy has on comprehension of a scientific explanation is relatively independent of the grade level of the subject tested.

Since the work of Orlando (1971) and Lunzer (1970) indicated that the ability to understand abstract analogies was related to the equilibration of Piaget's Stage of Formal operations, it was hypothesized that the presence of an analogy in a scientific explanation would aid comprehension of tenth grade subjects more than it would aid the comprehension of the eighth grade subjects since tenth grade subjects are near the age of equilibration of formal operations whereas eighth grade subjects are nearer the beginning of the onset of formal operations. An analysis of the results of the present experiment does not substantiate this hypothesis. However, an analysis of the analogy test scores at the two grade levels indicated that sixty-five percent of the tenth grade subjects met the criterion level for understanding the analogy while only twenty-nine percent of the eighth grade subjects met this same criterion (see Table 15). This finding appears to substantiate the findings of Orlando (1971) and Lunzer (1970) that the ability to understand an analogy increases as the subjects approach equilibration of formal operations.

TABLE 15

Percentage of Students Passing Criterion Level for Analogy Tests

GRADE 8

	Rank 3	Rank 6
Criterion	≥4*	≥6*
Phase Change	43.3	34.7
Compression	30.5	27.7
Diffusion	12.9	26.1
Mean	28.9	29.5

GRADE 10

	Rank 3	Rank 6
Criterion	≥4*	≥6*
Phase Change	67.1	77.8
Compression	70.9	76.7
Diffusion	42.0	55.5
Mean	60.0	70.0

* The criterion level for understanding the analogies was set at an analogy test score of greater than or equal to four and greater than or equal to six for argument rank three and argument rank six scientific explanations, respectively.

It may be noted that while most tenth grade subjects appeared to understand the analogy whereas most eighth grade subjects did not, the presence of the analogy did not aid the tenth grade students in their comprehension of the scientific explanation. This finding may indicate that immediate comprehension of the scientific explanation is independent of whether or not the analogy is understood. An analysis of the control group mean scores for the Compression and Diffusion argument rank six scientific explanations (see Table 15) indicates that eighth grade students also had a much more difficult time in understanding the scientific discourses. It may be that since the relations among the elements of the primary field of the analogy are the same as the relations among the elements of the scientific explanation, then those subjects who do not understand the relations of the scientific explanation can not understand them in the primary field of the analogy either since these subjects do not have these relations in their cognitive structure to match the relations in the scientific explanation or in the primary field of the analogy. If this is the case, then the use of an analogy in a scientific explanation would be of little value in aiding the student in understanding new learning material. Since the set of relations in the primary fields were isomorphic to the set of relations in the scientific explanations in the present study, it may be that subjects were unable to understand some of the relational concepts in the primary field and, therefore, were unable to transfer them to the scientific explanation.

SUMMARY OF RESULTS OF EXPERIMENT I

The design of this experiment involved the testing of the major hypothesis in twelve 2 x 7 (sex x format) factorial designs and four associated questions.

The major hypothesis was rejected in two cases but was not rejected in the other ten cases. The two cases in which the major hypothesis was rejected involved the argument rank six Phase Change scientific explanation. At the tenth grade level the "Pre" format mean was significantly less than the six other format means. At the eighth grade level the "Pre" and "SxS" format means were significantly less than the "control" group mean. No significant sex differences or sex x treatment interactions were observed. The results of the testing of the major hypothesis in Experiment I indicated:

1. the effect which the use of a concrete or conceptual verbal analogy in a scientific explanation has on immediate comprehension is independent of the sex of the subjects.
2. the use of a concrete or conceptual verbal analogy in a scientific explanation does not increase immediate comprehension of the scientific explanation in any of the six formats employed.
3. no one of the formats employed either increased or decreased immediate comprehension when a difference in sex is considered.

The results of this experiment supported the hypothesis that the use of a verbal analogy in a relatively short scientific explanation would have no significant effect on immediate comprehension. However, they did not support the hypothesis that the use of an analogy in a longer, more complex scientific explanation would increase immediate comprehension of the scientific explanation.

An analysis of the four associated questions indicated that the effect which the use of verbal analogies in a scientific explanation has on immediate comprehension is:

1. independent of the type of verbal analogy used since in no case was a significant difference observed between the criterion means of the concrete verbal analogy and the conceptual verbal analogy.
2. dependent on the topic of the scientific explanation; three of seventy-two cell means were significantly less than the control group means. These three cases all involved cells of the argument rank six Phase Change analogy as indicated above.
3. dependent on the length of the scientific explanation since the three cells noted above which were significantly less than the control group means occurred with the rank six argument but not with the rank three argument.
4. generally independent of the grade level of the subject except that the "SxS" format cell mean was significantly less than the control group mean for the argument rank six Phase Change analogy at the eighth grade level.

The anomalous results of the "Pre" format at the eighth and tenth grade levels and the "SxS" format at the eighth grade level for the argument rank six Phase Change scientific explanation appear to be the result of a topic x argument length x format interaction.

DISCUSSION OF RESULTS

Validity of Criterion Test

It should be noted that eighth grade subjects scored significantly lower on all criterion tests than tenth grade subjects. (See Table 16). Tenth grade subjects were tested after they had had the better part of a school year, in the ninth grade, studying qualitatively some aspects of the Kinetic Molecular Theory and were just about to engage in a quantitative study of some aspects of the theory. On the other hand, eighth grade subjects were tested at the end of the eighth grade just prior to a qualitative study of the Kinetic Theory in the ninth grade. These students had had very little formal study about the Kinetic Molecular Theory. The criterion score means obtained in this experiment are, therefore, congruent with expectations. This congruence tends to lend some credence to the validity of the criterion tests in measuring an understanding of the content of the scientific explanations.

TABLE 16

Control Group Mean Scores at Different Grade Levels

PASSAGE	GRADE		
	8	9	10
Compression	8.04	9.29	13.0
Diffusion	8.63	10.30	12.4

Sex Differences

It was hypothesized that there is no significant difference in immediate comprehension between male and female subjects when a verbal analogy is employed in a scientific explanation or when the scientific explanation is presented without the use of a verbal analogy.

In none of the twelve cases was a significant sex difference observed Therefore, the hypothesis was confirmed by the results of the present experiment. This result is in concert with the results of Dowell's (1968) study in which he employed visual analogies. While the results of Dowell's study and the results of Pilot Study I indicated that females tend to score higher on comprehension than males when an analogy is used in a scientific explanation, no such trend was found in the present experiment. In fact, in the present experiment, the opposite trend was noted since in nine of the twelve cases the means for males were numerically greater than the means for females. On the basis of Dowell's (1968) study, Pilot Study I, and the present experiment, it appears that no significant sex difference exists in immediate comprehension of a scientific explanation whether or not a visual analogy or a verbal analogy is employed in the scientific explanation.

Format Main Effect

The results of this experiment do not confirm the hypothesis that the format in which the scientific explanation and its respective primary analogical field are presented to the learner has a measurable effect on immediate comprehension, except for the "Pre" format for

Phase Change argument rank six at the tenth grade level and the "Pre" and "SxS" formats for the Phase Change argument rank six analogy at the eighth grade level where these formats resulted in significantly lower comprehension scores than the control groups. Whereas Rothkopf (1966) found that subjects who were given instructions to read the passage carefully scored significantly higher on a general test than the control group who were given the passage to read without such specific instructions, the use of a verbal analogy in the scientific explanation accompanied by instructions to relate the secondary field to the primary field in the present experiment did not indicate any such increase in general comprehension. In other words, the use of a verbal analogy does not appear to act as an "orienting direction" or focusing device in the same way as Rothkopf's verbal instructions. In fact, for the argument rank six Phase Change scientific explanation means for the "Pre" format at the tenth grade level and the "Pre" and "SxS" formats at the eighth grade level were significantly less than the corresponding control group means.

When Rothkopf (1966) placed test questions after the content to which they refer, subjects scored significantly higher on general test questions than subjects who were given these test questions before the content and those subjects who were not given any questions. In the present study, the placement of the primary field of a concrete verbal analogy after the scientific explanation did not significantly increase immediate comprehension of the scientific explanation, and the placement of the primary field of the analogy before the

scientific explanation decreased immediate comprehension in two cases and appeared to be detrimental to immediate comprehension in three of the four other cases with rank six arguments. On the basis of these observations it appears that the placement of the primary field of a concrete verbal analogy before and after the scientific explanation appeared to result in a similar pattern of comprehension as the placement of test questions, in that placing the primary field before scientific explanation was the less preferable of the two formats in terms of comprehension. However, placing the primary field after the scientific explanation did not increase immediate comprehension as did Rothkopf's test questions. Since none of the "Pre", "Post", Within" or "SxS" formats employed for the primary field increased immediate comprehension, it appears that the primary field of a concrete verbal analogy does not act as an "orienting direction" as do test questions.

A third class of orienting directions based on the advance organizer was also investigated in the present experiment. The primary field of concrete and conceptual verbal analogies were presented to subjects two days before the scientific explanation was read. This format of presentation is parallel to that employed by Ausubel (1960) and Ausubel and Fitzgerald (1961). These investigators found that if an advance organizer was presented two days before the passage was read, subjects scored significantly higher on a comprehension test than those subjects who read only the passage itself. In Pilot Study IV it was found that those subjects who read the primary field

of a concrete verbal analogy two days before reading the scientific explanation scored significantly higher on immediate comprehension than subjects who read only the scientific explanation. In the present experiment, no such significant difference was found in immediate comprehension between subjects who read either the primary field of the concrete verbal analogy or the postulates of the Kinetic Molecular Theory two days before reading the scientific explanation and those subjects who read only the scientific explanation. On the basis of the results obtained in the present experiment, it appears that the use of a concrete or conceptual verbal analogy in the advance organizer format does not function as an "orienting direction" for general comprehension.

A comparison of the hypothesized order of treatment means for concrete verbal analogies indicates:

1. none of the hypothesized significant differences were observed, and
2. while the hypothesized order was: "Pre" $<$ "Post" $\leq$ "Within" $\leq$ "SxS" $<$ "Advance Analogy", the actual numerical ranking of means was: Pre $\leq$ "SxS" $\leq$ Post $\leq$ Within $\leq$ Advance Analogy.

This numerical ranking indicates that the hypothesized order was reasonably accurate except the SxS format was lower in the order than predicted and none of the predicted significant differences were observed. It may be that the lower-than-predicted position of the SxS format in the rank order may have resulted from the fact that

students were given the choice of order in which to read the scientific explanation and the primary field. This choice may have resulted in some confusion on the part of subjects in making the decision as to which order to read the two fields of the analogy. The position of the Advance Analogy treatment in the rank order is as predicted and the Advance KMT was above that of the Advance Analogy in the rank order.

Since the results of the present experiment indicate that the presence of a primary field of a verbal analogy does not increase immediate comprehension over that obtained when the scientific explanation is presented alone, it appears that the primary field of a verbal analogy does not serve as an adequate subsumer for the scientific explanations. In fact it appears that in some cases the presence of the primary field appears to confuse the learner. This finding may result from the primary field increasing the information load when both it and the scientific explanation are required to be read. This hypothesis is pursued further in Experiment II where a primary field is presented by teacher demonstration using physical objects rather than through the written word.

The finding that seventy-nine percent of the subjects in Pilot Study III reported that they felt that the presence of the primary field of a verbal analogy aided them in understanding the scientific explanation even though the results of the experiment indicated that it did not appear to aid their immediate comprehension may indicate that the presence of a primary field serves some function other than increasing understanding and the subjects were unable to distinguish between that function and that of increasing understanding.

EXPERIMENT II - PHYSICAL ANALOGIES

Since the results of Experiment I indicated that the use of verbal analogies in a scientific explanation did not aid immediate comprehension of the scientific explanations, the present experiment was designed to determine whether the use of physical analogies in scientific explanations aid immediate comprehension of the scientific explanations. For this purpose, physical simulations for the argument rank six Compression and Diffusion scientific explanations used in Experiment I were constructed and demonstrated to experimental subjects immediately before they read the corresponding scientific explanation and responded to the criterion test. Control group subjects read only the scientific explanation and then responded to the criterion test.

RESULTS

The null hypothesis tested in this experiment was: there is no significant difference in criterion score means between the treatment group (physical analogy) and the control group (scientific explanation only). This hypothesis was tested in each of the two cases (Compression and Diffusion) using a one-tailed t-test with the level of significance set at 0.05. The results are presented in Tables 17 and 18.

TABLE 17

Summary of t-Test Results for Physical Analogy with Compression, Scientific Explanation

	Treatment Group: Simulation Plus Scientific Explanation (N = 22)	Control Group: Scientific Explanation Only (N = 21)
Criterion Mean	9.55	8.95
Variance	10.93	13.15

df = 41

t = 0.56 ($p > 0.05$)

F-Test for Homogeniety of Variance

$F = 1.22$ $p = 0.66$

TABLE 18

Summary of t-Test Results for Physical Analogy with Diffusion Scientific Explanation

	Treatment Group Simulation Plus Scientific Explanation (N = 33)	Control Group: Scientific Explanation Only (N = 24)
Criterion Mean	12.12	10.33
Variance	11.92	14.41

df = 55

$t = 1.85$ ($p < 0.05$)

F-Test for Homogeniety of Variance

$F = 1.3$ $p = .96$

For the Compression scientific explanation a t-value of 0.56 was obtained. This value is associated with a critical t-value of 1.68. Therefore, the null hypothesis was not rejected.

For the Diffusion scientific explanation a t-value of 1.85 was obtained. This value is associated with a critical t-value of 1.68. Therefore, the null hypothesis was rejected.

DISCUSSION OF RESULTS

The results of this experiment indicate that the use of a physical analogy in the Diffusion scientific explanation significantly increased immediate comprehension of that scientific explanation. However, while the treatment group mean for the Compression was numerically greater for the treatment group, it was not significantly greater.

It would appear that with certain scientific explanations accompanied by certain primary fields employing a physical simulation, immediate comprehension is increased significantly over that obtained when no simulation is employed in the explanation.

It was argued in Chapter II that the use of an analogy in a complex scientific explanation may aid the learner in ordering the elements and relations of the scientific explanation. Results of Experiment I indicated that the use of concrete and conceptual verbal analogies did not aid immediate comprehension of the Diffusion

scientific explanation whereas in the present experiment it appears that the use of a physical analogy did aid immediate comprehension of that explanation. Since no comparable increase was observed for the Compression scientific explanation in whicha physical analogy was employed, there appears to be an interaction between the topic of the explanation and the type of analogy employed in the explanation when immediate comprehension is the criterion. A comparison of the complexity of the two scientific explanations reveals a possible explanation for this interaction. The Diffusion scientific explanation involves three different kinds of molecules: light and heavy molecules of the gas mixture and air molecules (no distinction was made between the different molecules of which it is composed). On the other hand, the Compression scientific explanation involves only one kind of molecule. Hence, in reading the Diffusion explanation, the relative positions of the molecules of three gases must be kept in mind. In the case of the Compression explanation the relative positions of only one kind of molecule must be kept in mind. Furthermore, the rate of change of position of molecules in the Compression explanation is implied to be uniform whereas the rate of change of position of the molecules in the Diffusion explanation is different for different molecules. Also, in the Diffusion explanation, the relationship between the velocities of the two kinds of molecules and their respective masses is an inverse proportion whereas in the Compression explanation, the closeness of the molecules of the gas and the pressure

on the gas is a direct proportion. Since experience indicates that inverse proportionality is usually more difficult for students to comprehend than direct proportionality, it appears that the relationship involved in molecular movement in the Diffusion explanation is more complex than that of the Compression explanation. Furthermore, the Diffusion explanation involves multiple repetitions of the Diffusion process whereas the Compression explanation involves the compression process only once. Since the Diffusion explanation appears to involve greater complexity than the Compression explanation in terms of the number of different kinds of molecules to be considered, the rate of change of molecular position, the types of relationships involved in the processes, and the number of repetitions of the processes, subjects may require a visual physical model to order the elements and relations of the Diffusion explanation. On the other hand in the less complex Compression explanation the level of complexity of the elements and relations may not be great enough for the subjects to require such a model to order the elements and relations of the explanation. Since immediate comprehension was enhanced by the use of a physical analogy in the case of the Diffusion explanation but not in the case of the Compression explanation and the Diffusion explanation appears to be more complex than the compression explanation, it appears that the differential effect of the use of a physical analogy with different scientific explanations may be a result of differences in the complexity of scientific explanations.

The other variable which must be considered in rationalizing the different findings of the Compression and Diffusion passages is the nature of the primary fields. It may be that the primary field of the Diffusion analogy was in some way superior to that of the Compression analogy. Since no empirical research can be found indicating the variables involved in establishing the quality of a primary field, the question of the quality of the primary fields remains an open question. However, the two primary fields were equated in that they both were singular, strong, qualitative, concrete, physical analogies.

The finding that immediate comprehension of the Diffusion scientific explanation was not enhanced by the use of a conceptual verbal or a concrete verbal analogy in Experiment I may be a result of the inability of subjects to translate the written symbols of the verbally presented primary field into an ordered visualizable model through which the elements and relations of the Diffusion argument could be ordered. On the other hand, when a physical model was presented directly, the requirement of translating written symbols to a visualizable model was by-passed and immediate comprehension of this relatively complex scientific explanation was facilitated. This hypothesis is somewhat substantiated by the results of Pilot Study I in which a complex scientific explanation was presented using a physical analogy with one group and a verbal analogy with another. The group which was presented with the physical analogy scored significantly higher on immediate comprehension than the group

which was presented with the verbal analogy. Furthermore, Talley (1973) found that subjects who manipulated physical molecular models scored significantly higher on a content test than subjects who were presented the same subject material verbally. It, therefore, appears that the use of a physical analogy may be superior to the use of a verbal analogy to increase comprehension of a scientific explanation.

From a theoretical viewpoint, it appears that the primary field of a physical analogy serves the function of an appropriate subsumer for increasing immediate comprehension of a scientific explanation which is relatively complex in terms of the number of elements to be ordered and the nature of the relations between the elements.

EXPERIMENT III - EXTENDED VERBAL ANALOGY

Since the results of Experiment I indicated that the use of verbal analogies in relatively short scientific explanations (less than three hundred words) did not aid immediate comprehension of those scientific explanations, Experiment III was designed to determine whether the use of a verbal analogy in a longer scientific explanation aids comprehension of a longer scientific explanation. For this purpose a scientific explanation concerning the classification of matter and chemical change and an associated primary field of a conceptual verbal analogy were written and a criterion test was

constructed to measure comprehension of the scientific explanation. Treatment group subjects (selected on a random basis) read the scientific explanation and the primary field, in that order, and control group subjects read only the scientific explanation. After each group had read their respective passages, they responded immediately to the criterion test items.

The major hypothesis to be tested in this experiment was: there is no significant difference in criterion score means between the treatment group (verbal analogy) and the control group (scientific explanation). This hypothesis was tested using a one-tailed t-test with the level of significance set at 0.05. The results are shown in Table 19. A t-value of 0.37 was obtained. This value is associated with a probability of 0.71 that the difference in means is due to sampling error. Therefore, the null hypothesis was not rejected.

DISCUSSION OF RESULTS

The results of the present experiment tend to support and extend some of the dimensions of Experiments I. The present experiment supports the finding in Experiment I that the use of a verbal analogy in a scientific explanation does not appear to significantly increase immediate comprehension of the scientific explanation over that obtained when only the scientific explanation is read. Since the results of Experiment I indicated no significant increase in immediate comprehension

TABLE 19

Summary of t-Test Results for Extended Verbal Analogy with Classification of Matter Scientific Explanation

	Treatment Group (Discourse with Analogy) (N = 41)	Control Group (Discourse Only) (N = 40)
Criterion Mean	9.35	9.54
Variance	6.39	4.05

df = 79

t = 0.37 ($p > 0.05$)

F-Test for Homogeniety of Variance

F = 1.59 P = 0.16

between subjects which read a scientific explanation containing a verbal analogy and subjects which read only the scientific explanation and the same result was obtained in the present experiment which employed a much longer scientific explanation, the present experiment extends the findings of Experiment I to longer scientific explanations. Furthermore, since Experiment I used two lengths of scientific explanation and the present experiment used yet a longer scientific explanation and both experiments indicate that comprehension is not aided by the presence of a verbal analogy, it appears that the effect, if any, which the use of a verbal analogy has on increasing comprehension of the scientific explanation may be independent of the length of the scientific explanation. The hypothesis that the use of a verbal analogy in a scientific explanation functions to decrease the information load by acting as a projective model for the new learning material and hence increasing comprehension of the scientific explanation was not confirmed.

Whereas the topics of the scientific explanations of Experiment I were in each case within the realm of the Kinetic Molecular Theory, the topic of the scientific explanation in this experiment dealt with the classification of matter and chemical change. The result that no significant difference between treatment and control groups emerged in this experiment gives support to the general finding in Experiment I that the results obtained are independent of the topic of the scientific explanations. This statement must be qualified since in Experiment I the Phase Change analogy in the "Pre" and "SxS" positions did appear to interact with the topic of the scientific explanation.

In Experiment I the logical form of the discourse was limited to that of a hypothetical syllogism whereas in the discourse in Experiment III the general form was that of a classificatory system. The result that similar outcomes were obtained in both cases lends some generality to the findings under different types of argument form.

Probably one of the more significant variables which was checked out in Experiment III was that of the timing of the the presentation in terms of student background. The subjects involved in Experiment III were very carefully prepared in terms of their background knowledge so that the next topic to be taught in the sequential development of their science program was the classification of matter. At this point the experiment was administered to the subjects. Again, as in Experiment I, no significant difference was obtained between the experimental and control groups. These findings indicate that the no-significant-difference results obtained appear to be somewhat independent of student readiness to receive the content, except as indicated earlier, for the Phase Change explanation with the primary field in the "Pre" position.

CHAPTER V

SUMMARY, IMPLICATIONS, AND SUGGESTIONS FOR FURTHER RESEARCH

SUMMARY

The purpose of this study was to determine whether the use of particular types of verbal analogy and a particular type of physical analogy in a written scientific explanation has a measurable effect upon the learner's immediate comprehension of the explanation when it is read.

The present study consisted of three separate experiments which will be summarized in turn. Then an over-all summary dealing with the major parameters of the study is presented.

EXPERIMENT I - VERBAL ANALOGIES

A sample consisting of 1,258 tenth grade students and 814 eighth grade students was employed.

Three different physical phenomena were chosen as the content of six scientific explanations: liquid-vapour equilibrium in a closed system (Phase Change) compression of a gas (Compression), and diffusion of a mixture of gases (Diffusion). For each phenomenon two explanations based on the Kinetic Molecular Theory were written: one short

(approximately one hundred and fifty words) and one relatively longer (approximately three hundred words). For each of the six scientific explanations, a primary field of a concrete verbal analogy and the postulates of the Kinetic Molecular Theory were written. Seven treatments were then constructed for each of the six scientific explanations as follows:

1. five treatments were generated by placing the primary field in five different positions with respect to the scientific explanation, so that subjects would read the primary field and scientific explanation in one of five different sequences:

   (i) The primary field was read immediately before the scientific explanation was read (Pre).

   (ii) The primary field was read immediately after the scientific explanation was read (Post).

   (iii) A paragraph of the scientific explanation was read followed by the corresponding paragraph of the primary field (Within).

   (iv) The sequence in which the primary field and scientific explanation were read was left to the choice of the reader by placing the primary field to the right of the scientific explanation on a two column page (SxS).

   (v) The primary field was read two days before the scientific explanation was read (Adv. Anal.).

2. a sixth treatment was generated by having subjects read the postulates of the Kinetic Molecular Theory two days before the scientific explanation was read (Adv. KMT).
3. in the seventh treatment, subjects read only the scientific explanations (Control).

In treatments 1 - 5, after subjects had read the analogy, they responded to the analogy test and the criterion test designed to measure their understanding of the analogy and scientific explanation, respectively. Subjects in the sixth and seventh treatments, after completing the reading required, responded to the criterion test only.

Since the above procedure was employed for each of the six scientific explanations, forty-two different treatments (six explanations x seven treatments per explanation) were generated. Each of the forty-two treatments was compiled into two identical booklets, one for males and one for females. One set of the forty-two treatments was administered on a random basis to males, while the other set was administered on a random basis to females.

The results of the criterion test scores were analyzed using six analysis of variance designs.

The procedure outlined above was carried out at two different grade levels: eight and ten. Hence, this experiment consisted of

eighty-four treatment cells. Some modifications were made in the random distribution of treatments at the eighth grade level as requested by the schools' administration.

The hypothesis tested and four associated questions examined along with a summary of the results follows.

Hypothesis

The hypothesis tested was: there is no significant difference in criterion score means between sexes or among formats and there is no significant sex x format interaction effect. The results associated with this hypothesis were as follows.

Sex main effect. In none of the twelve cases (three contents x two argument ranks x two grades) was a significant sex main effect noted. In a study by Dowell (1968) in which visual analogies were employed and in Pilot Study I in which verbal and physical analogies were employed there were indications that females tend to score higher on comprehension than males when an analogy is used in a scientific explanation. No such trend was observed in the present experiment. In fact, in the present experiment, in nine of the twelve cases, the means for males were numerically greater than for females. On the basis of the results of Dowell's (1968) study, Pilot Study I, and the present experiment, it appears that no sex difference exists in comprehension of a scientific explanation whether or

not a visual analogy or a verbal analogy is employed in the scientific explanation.

Since no significant sex x format interaction effects were noted in any of the twelve cases, it appears that no one of the formats employed increases or decreases immediate comprehension when a difference in sex is considered.

Format main effect. In only two of the twelve cases was a format main effect observed. They both occurred for the Phase Change analogy at the argument rank six level. Further analysis using the Newman-Keuls Test for differences among means indicated that at the tenth grade level the "Pre" format mean was significantly less than the means of the six other formats. At the eighth grade level the "Pre" and "SxS" format means were significantly less than the control mean but not significantly less than the other format means. Since the formats which yielded means significantly lower than the corresponding control groups all occurred for the argument rank six Phase Change scientific explanation, it appears that there was an interaction among format, length of scientific explanation and topic.

Frase (1970) in summarizing the research on mathemagenic behaviours, indicated that one of the classes of mathemagenic behaviour is "orienting direction." The present experiment was designed to determine whether a verbal analogy could act as an "orienting direction" for general comprehension of a scientific explanation. For this purpose, the primary field of a verbal analogy

was placed in six different positions with respect to each of the six scientific explanations. The primary field was placed before, after, within and beside the scientific explanation parallel to the form of the design of Rothkopf (1966) in which he found that the placement of test-like questions before, within, and after the passage had differential effects on comprehension of the passage. Also, two kinds of primary fields were placed in the advance organizer position to parallel the form of the design of Ausubel (1960) and others (Ausubel and Fitzgerald, 1961; Ausubel and Youseff, 1963; Grotelueshen and Sjogren, 1968; Merrill and Stulurow, 1965) in which advance organizers were successfully used as an "orienting direction" to increase comprehension. Since, in Experiment I, for sixty-nine of the seventy-two cells no significant increase in immediate comprehension of the scientific explanation was observed and in the other three cases, a significant decrease in comprehension was observed when the means of the scientific explanations in which analogies were employed were compared to the corresponding control group means, it appears that the verbal analogies did not function as an "orienting direction" to increase immediate comprehension over that obtained by the control group which read only the scientific explanation.

While the hypothesized order of treatment means was: pre $<$ post $\leq$ within $\leq$ SxS $<$ advance analogy, the observed order was: Pre $\leq$ SxS $\leq$ post $\leq$ within $\leq$ advance analogy. The numerical ranking indicates that the hypothesized order was reasonably accurate except the "SxS" format was lower in the order than predicted and none of the predicted significant differences were observed.

It was concluded on the basis of the results of this experiment that the null hypothesis was not rejected in ten of the twelve cases but was rejected for the argument rank six Phase Change passage at both grade levels.

Associated Questions

1. Type of Verbal Analogy.

In the present experiment both concrete and conceptual primary fields were employed in the "advance" format (i.e., the primary field was read two days before the scientific explanation was read). The primary field used in the "Advance Analogy" format employed concrete objects as the analogates to be compared with the analogates of the scientific explanation while the primary field used in the "Advance KMT" format employed conceptual objects (the Kinetic Molecular Theory) as the analogates to be compared with the analogates of the scientific explanation. Since no significant differences in immediate comprehension were observed between the two kinds of analogies in the twelve cases tested, it would appear that the effect which the use of a verbal analogy in a scientific explanation has on comprehension of the scientific explanation is independent of the type of verbal analogy employed in this experiment.

While Heidbreder (1947) found that concrete concepts were more readily comprehended than abstract concepts and Ennis (1965) found that concrete concepts were more readily manipulated in problems of logic, it appears that there is no significant effect on immediate comprehension when concrete objects as opposed to conceptual objects are employed as the analogates in the primary field of a verbal analogy.

2. Topic of Scientific Explanation

Since significant differences were observed between treatment group means and control group means for the argument rank six Phase Change topic but no significant differences were observed for the Comprehension and Diffusion topics, it would appear that the effect which the use of a concrete verbal analogy in a scientific explanation has on immediate comprehension of a scientific explanation is not independent of the topic of the scientific explanation. However, when the results for the argument rank three Phase Change passage were analyzed, no significant differences were observed. Since significant differences were observed for the rank six Phase Change passage but none were observed for the argument rank three Phase Change argument, and no significant differences were observed for the Compression or Diffusion topics, it appears that there may be an interaction between

topic and length of scientific explanation when immediate comprehension is the criterion.

3. Length of Scientific Explanation.

It was argued that the use of a verbal analogy in a relatively short scientific explanation would have little or no effect on immediate comprehension of the short scientific explanation since the complexity of the argument is not great enough to require an external model to order the elements and relations of the explanation. This argument was substantiated by the results of the present experiment since no significant differences were observed between treatment groups which were administered analogies and their corresponding control groups which were administered argument rank three scientific explanations only. However, the hypothesized increase in immediate comprehension for treatment groups for which rank six arguments were employed over their corresponding control groups was not realized. In fact, in three of the thirty-six treatment groups for which verbal analogies were employed in longer scientific explanations, immediate comprehension was significantly less than for the corresponding control groups. No significant differences were observed between treatment and control group for the other thirty-three treatment groups. Furthermore, when the means for the treatment groups were compared with corresponding control group

means, six means were numerically lower while sixteen were greater and two were the same for the shorter scientific explanations. When the same comparison was made for the longer scientific explanations nineteen means were numerically less, four were greater and one was the same. Hence it appears that the use of a verbal analogy in a scientific explanation tended to aid the shorter scientific explanations more than the longer ones. It therefore appeared that the presence of the primary field in a longer scientific explanation tended to increase the information load rather than decrease it.

Since the results of the experiment indicated a significant decrease in immediate comprehension in comparison to the control group means for the "Pre" format at both grade levels and the "SxS" format at the eighth grade level for the Phase Change topic at the argument rank six level but no significant differences were noted for the same topic at the shorter argument rank three level, it appears that the effect which the use of a verbal analogy in a scientific explanation has on immediate comprehension of the scientific explanation is not independent of the length of the scientific explanation for the Phase Change topic. As there were no significant differences between treatment group means and control group means for argument rank three or argument rank six scientific explanations for the Compression and Diffusion topics, it appeared that for these two topics the effect which the use of a verbal analogy in the scientific explanations has on immediate comprehension is independent of the length of these scientific explanations.

Since it appeared that subjects were most familiar with the Phase Change passage, it appeared that the presence of the primary field of an analogy in the "Pre" format at the eighth and tenth grades and "SxS" format at the eighth grade level resulted in confusing subjects about a topic with which they were somewhat familiar. It may be that for relatively complex scientific explanations with which the subject is already somewhat familiar, the placement of the primary field in the "Pre" or "SxS" format tends to hinder the students immediate comprehension of the subject matter.

4. Grade Level of Subjects.

At both grade levels the criterion score means of the "Pre" format for the argument rank six Phase Change scientific explanations were significantly less than the corresponding control group criterion score means. At the eighth grade the criterion score mean of the "SxS" format for the same scientific explanation was significantly lower than the control group mean. No other significant differences were observed between treatment and control group means at either grade level. Since the pattern of significant differences between treatment and control groups are identical except for the "SxS" format mean at the eighth grade level, it appears that the effect which a verbal analogy has on immediate comprehension is relatively independent of the grade level of the subjects tested.

An analysis of the analogy test scores at the two grade levels indicated that sixty-five percent of the tenth grade subjects met the criterion level for understanding the analogy while only twenty-nine percent of the eighth grade subjects met this same criterion. This result appears to substantiate the findings of Orlando (1971) and Lunzer (1970) that the ability to understand an analogy increases as the subjects approach equilibration of Piaget's stage of format operations. The difference in levels of understanding does, however, seem to indicate that immediate comprehension of the scientific explanation in which a verbal analogy is employed is independent of whether or not the analogy is understood. Since the level of understanding of the analogy appears to also be reflected in the level of understanding of the scientific explanations when the two grade levels are considered, it may be that if the relations in the scientific explanation are not understood, they may not be understood in the primary field of the analogy either. If this is a correct inference, the use of a verbal analogy would have no effect on increasing comprehension of the scientific explanation.

EXPERIMENT II - PHYSICAL ANALOGIES

The sample for this experiment consisted of one hundred students enrolled in a ninth grade general science course.

Since the results of Experiment I indicated that the use of verbal analogies in scientific explanations did not aid immediate comprehension of the scientific explanations, Experiment II was designed to determine whether the use of physical analogies in scientific explanations aid immediate comprehension of the scientific explanations. For this purpose, physical simulations were constructed for the argument rank six Compression and Diffusion scientific explanations used in Experiment I. Each simulation was then demonstrated to the experimental group subjects (chosen at random from within classes) immediately before they read the corresponding scientific explanation and responded to the corresponding criterion test. Control group subjects read only the scientific explanation and then responded to the corresponding criterion test.

RESULTS

The null hypothesis tested in this experiment was: there is no significant difference in criterion score means between the treatment group (physical analogy) and the control group (scientific explanation analogy). This hypothesis was tested in each of the two cases: Compression and Diffusion. For the Compression and Diffusion scientific explanations, t-values of 0.56 and 1.85, respectively, were obtained. These values are associated with a critical t-value of 1.68. Therefore the null hypothesis was rejected for the Diffusion scientific explanation but was not rejected for the Compression scientific explanation.

The results of this experiment indicated that the use of a physical analogy in the Diffusion scientific explanation significantly increased immediate comprehension over that obtained by the control group. However, no such significant difference was observed in the case of the Compression scientific explanation although the treatment group mean was numerically greater than the control group mean.

An analysis of the two scientific explanations revealed that the Diffusion scientific explanation appeared to be more complex than the Compression scientific explanation in that there were more elements involved and the type of relations among the elements were more complex. It therefore appears that the use of a physical analogy in a scientific explanation may result in increased immediate comprehension when the scientific explanation is relatively complex but does not result in increased comprehension when the scientific explanation is not complex.

It was also noted that when these same two scientific explanations were accompanied by primary fields of concrete or conceptual verbal analogies no significant differences were observed between treatment and control groups. It therefore appears that there may be an interaction between the topic and the type of analogy employed. It was hypothesized that this apparent interaction may be a result of an interaction between the complexity of the scientific explanation and the type of analogy employed. That is, when a physical analogy is employed with a relatively complex scientific explanation an increase in immediate comprehension over that obtained by the control group is

noted whereas no such increase is observed for less complex explanations or when a concrete or conceptual analogy is employed. Since Experiment II used subjects at the ninth grade level whereas Experiment I used subjects at the eighth and tenth grade levels, the above discussion assumes no third order interaction involving grade level, type of analogy and topic.

Talley (1973) found that subjects who manipulated physical molecular models scored significantly higher on a content test than subjects who were taught didactically. On the basis of the results of Experiment II, it appears that the use of physical analogies in teacher demonstrations may also increase comprehension of relatively complex scientific explanations.

Interpreting the results of Experiment II in terms of Ausubel's theory of Meaningful Verbal Learning, it appears that the use of a physical simulation previous to presenting a relatively complex scientific explanation may incorporate in the cognitive structure an appropriate subsumer to increase understanding of the scientific explanation.

EXPERIMENT III - EXTENDED VERBAL ANALOGY

The results of Experiment I indicated that the use of verbal analogies in relatively short scientific explanations (less than three hundred words) did not aid immediate comprehension of those

scientific explanations. Experiment III was designed to determine whether the use of a weak verbal analogy in a longer scientific explanation (eight hundred and twenty-three words) aids in immediate comprehension of a longer scientific explanation. For this purpose, a scientific explanation concerning the classification of matter and chemical change and an associated primary field of a conceptual verbal analogy were written and a criterion test was constructed to measure comprehension of the scientific explanation. The sample for the experiment consisted of eighty-one students enrolled in a ninth grade general science course. Treatment group subjects (selected on a random basis) read the scientific explanation and the primary field, in that order, and control group subjects read only the scientific explanation. After each group had read their respective passages, they responded immediately to the criterion test items.

The null hypothesis which was tested in this experiment was: there is no significant difference in criterion score means between the treatment group (conceptual verbal analogy) and the control group (scientific explanation only). A t-value of 0.37 was obtained. This value is associated with a probability of 0.36 that the difference in means is due to sampling error. Therefore, the null hypothesis was not rejected. The results of this experiment did not support the hypothesis that the use of a conceptual verbal analogy in an extended scientific explanation aids in immediate comprehension of the extended scientific explanation.

The results of Experiment III support the finding in Experiment I that the use of a verbal analogy in a scientific explanation does not appear to significantly increase immediate comprehension of scientific explanation over that obtained when only the scientific explanation is read. Since Experiment I employed short scientific explanations of approximately one hundred and fifty words and longer ones of approximately three hundred words and the present experiment employed a scientific explanation of eight hundred and twenty-three words, and no significant increase in immediate comprehension was noted in either of the two experiments, it appears that the effect which the use of a verbal analogy in a scientific explanation has on increasing immediate comprehension is independent of the length of the scientific explanation.

Whereas,the topics of the scientific explanations in Experiment I were chosen from within the realm of the Kinetic Molecular Theory, the topic of the scientific explanation in Experiment III dealt with the classification of matter. Since no significant increases in immediate comprehension were noted in either case, it appears that the effect which the use of a verbal analogy in scientific explanations has on increasing immediate comprehension appears to be independent of the topic of the scientific explanation.

Since the readiness of the subjects to receive the information in the scientific explanation was carefully developed in Experiment III but no such effort was made in Experiment I, it appears that the effect

which the use of a verbal analogy in a scientific explanation has on increasing immediate comprehension appeared to be independent of the readiness of subject to receive the new learning material.

OVERVIEW SUMMARY

Surveys of the use of analogy in science and chemistry text books (Beller, 1954; Scott, 1964) and the proliferation of physical models for the teaching of science coupled with statements by science educators (Asimov,1959; Kamenetsii, 1966) indicate a belief on the part of science educators that the use of analogy in scientific explanations facilitates student comprehension of the explanation. The present study was designed to evaluate whether or not this belief is substantiated empirically when some selected analogies are used in textbook-like presentations or in classroom teacher demonstrations.

Since the number of different analogies employed in science teaching is very large and the nature of them is diverse with respect to the type of analogy employed, the substantive sphere in which they are employed, the format of presentation, and mode of presentation, the present study was, by practical necessity, delimited with respect to each of these factors. The number and types of analogies investigated in the present study were five selected, singular, strong, qualitative, verbal analogies (two conceptual and three concrete) and two selected, singular, strong, qualitative physical analogies. The sample of

analogies chosen from within these classes of analogies is limited to a very small fraction of those possible. However, the few verbal analogies selected were ones that science textbook authors presumably believed would increase student comprehension of the associated scientific explanation since they had apparently used them for this purpose in their books. Furthermore, a panel of practicing teachers shared this belief and also considered all the analogies employed in the present study to represent the kinds of analogies used in the junior high school chemistry curriculum by teachers and authors for the purpose of facilitating understanding.

As well as delimiting the types of analogies employed in the present study, the substantive sphere in which analogies are used was delimited to explanations associated with the Kinetic Molecular Theory and in explanations of the structure of matter and chemical change. These substantive spheres were chosen because they both are included in the junior high school curricula of Alberta and Britich Columbia and Scott (1964) found that the Kinetic Molecular Theory was the topic for which authors of chemistry textbooks most frequently invoke the use of analogy in their explanations to facilitate understanding.

In brief, it must be emphasized that this study was designed to evaluate in some detail only three very specific subsets of the universal set of analogies used in science education and even within these sets the sample employed was very limited.

Therefore, the results of this study are not generalizable beyond the specific subset of analogies tested and caution should be exercised when generalizing the results to the domain of the specific subsets tested.

It should also be emphasized that the present study evaluated the effect of the use of some selected analogies which adults perceived as facilitating children's understanding of scientific explanations. The results of this study are not generalizable to the kinds of analogies which children might actually prefer to use in their comprehension processes. However, it should be pointed out that seventy-nine percent of the subjects in Pilot Study III did perceive the analogies used in the present study as facilitating their comprehension.

The problem to which this study was directed was: does the use of an analogy in a written scientific explanation have a measurable effect on the learner's immediate comprehension of the explanation when it is read? Within the delimitations and limitations and the limited sample of the study the results appear to indicate that, in general, the use of a verbal analogy in a scientific explanation does not have a measurable effect on the learner's immediate comprehension of the scientific explanation when it is read. However, if the primary field is in the "Pre" format when either eighth or tenth grade students are the subjects or if the primary field is in the "SxS" format when eighth grade students are the subjects, and if the scientific explanation is based on concepts with which subjects are familiar, immediate comprehension is likely to be less than that obtained when only the scientific explanation is read.

On the other hand, when physical analogies are employed in relatively complex scientific explanations, an increase in immediate comprehension was observed but no significant increase was observed when a physical analogy was employed in a less complex scientific explanation.

On the basis of the result of the three experiments involved in the present study it was found that:

1. There was no significant difference in immediate comprehension of the scientific explanations between sexes whether or not the scientific explanation was accompanied by the corresponding primary field of a verbal analogy.
2. When the primary field of a verbal analogy was placed before, after, within, beside and two days before the scientific explanation, the primary field did not function as an "orienting direction" to increase immediate comprehension of a scientific explanation.
3. With the exception of the argument rank six Phase Change topic with the primary field in the "Pre" and "SxS" positions, the effect which the use of verbal analogies had on immediate comprehension of the scientific explanation was independent of the topic of the scientific explanation.
4. With the exception of the argument rank six Phase Change scientific explanation in Experiment I, the effect which the use of a verbal analogy has on immediate comprehension of a scientific explanation was independent of the length of the scientific explanation.
5. With the exception of the "SxS" format for the argument rank six scientific explanation of Phase Change at the eighth grade level, the effect which a verbal analogy has on immediate comprehension of a scientific explanation is independent on the grade level of the subjects tested.

6. With the exception of the "Pre" format at the eighth and tenth grade level and the "SxS" format at the eighth grade level for the argument rank six Phase Change scientific argument, the effect which a verbal analogy has on immediate comprehension of the scientific explanation is independent of whether or not the analogy was understood by the subjects for the "Pre", "Post", "Within", "SxS" and "Adv. Anal." formats.
7. With the exception of the "Pre" format at the eighth and tenth grade level and the "SxS" format at the eighth grade level for the argument rank six Phase Change scientific explanation, the effect which the use of a verbal analogy had on immediate comprehension of the scientific explanation appeared to be independent of the readiness of the subject, in terms of background information, to receive the scientific explanation.
8. With the exception of the "Pre" format at the eighth and tenth grade level and the "SxS" format at the eighth grade level for the argument rank six Phase Change scientific explanation, the effect which the use of a verbal analogy has on immediate comprehension is independent of the type of verbal analogy when the "Advance" format or "Post" format is employed.
9. When a physical analogy is used in a relatively complex scientific argument immediate comprehension of the scientific

argument is significantly greater than that obtained when only the scientific explanation is read. However, no such significant difference was observed when a physical analogy was employed in a less complex scientific explanation.

The anomalous results of the "Pre" format at the eighth and tenth grade levels and the "SxS" format at the eighth grade level for the argument rank six Phase Change scientific explanation appear to be a result of the interaction of several variables. A comparison of "Pre" format means with their corresponding control group means for rank six scientific explanations indicates that in five of six cases the "Pre" format mean was numerically less than the control group mean. The same comparison for rank three scientific explanations indicates only one of six "Pre" format means is less than the corresponding control group mean. Hence the "Pre" format appears to depress means for rank six scientific explanations but not for rank three scientific explanations. Hence, there appears to be an interaction between format and argument length. Furthermore, while the "Pre" format means for the Compression and Diffusion topics at the rank six argument level are numerically less than their control group means, they are not significantly less. Therefore, the topic of the scientific explanation appears to be a factor in the significantly lower mean of the "Pre" format. Hence, it would appear that the significantly lower mean for the argument rank six Phase Change scientific explanation with the primary field of the verbal analogy in the "Pre" format is a result of a format x argument length x topic interaction.

A similar examination of the "SxS" format at the eighth grade level indicates that in all three argument rank six cases the "SxS" format means were numerically less than the corresponding control means while at the argument rank three level only one of the three "SxS" format means was numerically less than the corresponding control means. Hence, there appears to be a format x argument length interaction. Furthermore, since no significant differences between the "SxS" format means and their control means occurred for the Compression and Diffusion topics it appears that the topic of the scientific explanation is also a factor. It would appear that the significantly lower mean for the argument rank six Phase Change explanation with the primary field of the verbal analogy in the "SxS" format is a result of a format x argument length x topic x grade interaction.

Some insight onto the cause of these interactions is gained by examining the subjects' background in terms of their familiarity with concepts in the scientific explanations. An historical examination of subjects' backgrounds indicates that they should be more familiar with the concepts of the Phase Change scientific explanation than with those in the other two topics since the concepts of evaporation and condensation are taught at earlier grade levels in the science

curriculum while those of Compression and Diffusion are not part of the earlier curriculum. It therefore appears that when the concepts of the scientific explanation are somewhat familiar to subjects and the "Pre" format is employed at the eighth and tenth grade levels or in the "SxS" format at the eighth grade level with approximately three hundred word scientific explanations, the interaction is likely to occur.

It may be that the "Pre" and "SxS" formats result in specific learning rather than general comprehension of the scientific explanation as Rothkopf found when he placed test questions before a passage to be read. Since the concepts of the scientific explanation were already somewhat familiar to the subjects and they focused on these specifics rather than the overall relationships, their general comprehension was actually limited by the "Pre" format coupled with a scientific explanation which contained familiar concepts.

Since it appears that the use of a verbal analogy in at least the "Pre" and "SxS" formats with a topic which students are somewhat familiar with results in a significant decrease in immediate comprehension and has no effect on the comprehension of topics with which the subjects have some background, it may be that for completely new learning material the use of an analogy would increase comprehension. In other words, there may be an inverse relation between familiarity with subject material and comprehension when an analogy is employed in a scientific explanation. Completely new learning material was

not employed in the present study since the object of this study was to attempt to simulate classroom learning conditions where new learning is based at least partially on past learning experiences.

Since it was found that immediate comprehension of a scientific explanation is not increased over that attained by the control group when a verbal analogy is employed in the scientific explanation, it appears that the primary field of a verbal analogy does not serve as an adequate subsumer for the scientific explanation. However, since it was found that immediate comprehension of a relatively complex scientific explanation was significantly increased over that attained by the control group, it appears that physical simulations serve to establish suitable subsumers in the cognitive structure for relatively complex scientific explanations.

Since seventy-nine percent of the subjects in Pilot Study III reported that they felt that the presence of the primary field of a verbal analogy did aid them in understanding the scientific explanation although the results indicated that it did not appear to aid immediate comprehension, it may be that the primary field was of assistance to them in some way. It may be that the use of a verbal analogy in a scientific explanation acts in a similar manner to a catalyst in a chemical reaction. The catalyst acts as an intermediary in the reaction but does not change the end-product results. In the present study only the end-product of the learning experience was measured. However, it may be that the analogy facilitated some intermediate stages in the learning process but

did not affect the overall comprehension. Since ample time was given for subjects to complete the task in Experiments I and III, any increase in efficiency of learning in terms of time or expenditure of energy would not have been detected. For example, the use of analogy in a scientific explanation may facilitate the process of assimilation, hence students may feel that they are able to relate the material to their cognitive structure. However, if an analogy does not also facilitate the accommodation process the analogy will not result in an increase in comprehension since it is in the accommodation stage that cognitive structures are changed with the result that new learning occurs.

It should be pointed out that the results of the present study are limited to use of singular, qualitative strong analogies in scientific explanations. Other forms of analogy are yet to be investigated.

IMPLICATIONS FOR SCIENCE TEACHING

Any implications for science teaching based on the findings of the present study should be made with caution. The findings concerning immediate comprehension of a scientific explanation are limited to the grade levels used in the study, to scientific explanations related to topics in chemistry which are dealt with at a qualitative level, to scientific explanations which are read, and to singular, qualitative, strong verbal and physical analogies.

On the basis of the results of the present study it would appear that the belief that science educators have that the use of a verbal or a physical analogy in a scientific explanation increases comprehension of the scientific explanation must be tempered. The results of the present study indicate that if an analogy is to be used in a scientific explanation by science teachers to increase immediate comprehension of the scientific explanation then a physical analogy should be employed rather than a verbal analogy. Furthermore, it would appear that use of a physical analogy is not warranted except when the scientific explanation is relatively complex. Since in no case in the present study was there any indication that the use of a verbal analogy in a scientific explanation can increase immediate comprehension over that obtained when the scientific explanation alone is presented, it appears that the use of a verbal analogy to increase immediate comprehension does not appear to be warranted. Indeed, when the primary field of a concrete verbal analogy is presented to the learner before or beside the scientific explanation a significant decrease in immediate comprehension of the scientific explanation may result. It appears that this decrease in comprehension is most likely to occur if the content of the scientific explanation is relatively familiar to the student.

Since not all types of verbal analogies have been investigated in the present study, nothing can be said about the effect of other types of verbal analogies on immediate comprehension nor of the possibility that the use of a verbal analogy may play a role in

learning other than that of effecting comprehension. Since the use of verbal analogies in scientific explanations may serve a number of functions considered to be important in the learning process other than that of increasing immediate comprehension, (e.g. increasing motivation, increasing interest, increasing the rate of assimilation, and increasing the rate of learning), the findings of the present study do not preclude the use of even the verbal analogies employed in the present study from use in the classroom. For instance, in Pilot Study III a questionnaire was administered to forty-three tenth grade students after they had read verbal analogies similar to those employed in Experiment I and had responded to the test items. Seventy-nine percent of the students indicated that they felt that the presence of the primary field helped them to understand the scientific explanation better. However, an analysis of the difference in means between the groups which read the verbal analogy and the groups which read only the scientific explanation indicated that the latter group mean was significantly greater than that of the former. Since students felt that the use of an analogy increases their understanding of the scientific explanation, it may be serving some function in the learning process other than that of increasing immediate comprehension. Bruner, Goodnow and Austin (1956) found that after students had learned a new concept they appeared to search for some means whereby they could check whether or not they had learned the concept correctly. When a student is given an analogy in a new learning task, he has two systems--the primary and secondary--which are structurally similar in that they

contain corresponding elements and relationships. The student may check his comprehension of the structure of the new learning task by comparing point for point the elements and/or relationships of the new learning task, as he comprehends them, with those in the primary field by mapping the elements and/or relationships from the secondary field onto the primary field. While the results of the present study indicate that this procedure does not appear to lead to increased comprehension, it may be that it satisfies the students' need for an external checking mechanism.

Perhaps the process of analogizing, outlined above, does not lead to increased comprehension because if the student misconstrues a relationship in the secondary field he will misconstrue that same relationship in the same way in the primary field. Hence, he will think the verbal analogy has led him to increased comprehension; however, it will have acted only as a checking device wherein errors in comprehension are as readily transferred as correct comprehensions.

If analogies are used in classroom teaching, several limitations of the use of analogy should be kept in mind. First, argument by analogy can not be considered to be a valid basis for forming conclusions. The analogy can be used to formulate hypotheses but these hypotheses must be subjected to empirical test before any validity can be attached to them. If analogies lead to over-generalization without empirical check, an error in the valid use of analogy has been committed. Second, if extensive use is made of

analogies in which the behavior of inanimate objects is related to human traits, the student may begin to attribute human qualities to inanimate objects. This anthropomorphic thinking should be avoided in teaching young people science since it misrepresents the nature of scientific thought. Third, if the teacher employs a verbal analogy to increase immediate student comprehension of the new learning material, the present study indicates that there may be some question as to whether an increase in immediate comprehension is an appropriate goal for the use of such analogies.

If, however, a teacher is to use a verbal analogy in scientific explanations for some objective other than increasing immediate comprehension but is concerned with the effect such use may have on comprehension, then the results of the present study indicate, keeping the delimitations and limitations of the present study in mind, that he can be guided by the following findings:

1. There are no sex differences in immediate comprehension when a verbal analogy is used in a scientific explanation.
2. As a cautionary measure, when a verbal analogy is used in a scientific explanation which is to be read the primary field should not be placed in the "Pre" or "SxS" format especially if the content of the scientific explanation is somewhat familiar to the learner.
3. If the topic of the scientific explanation is relatively unfamiliar to the learner then the effect which the use of a verbal analogy has on immediate comprehension is independent of the topic.

4. The effect which a verbal analogy has on comprehension is independent of the length of the scientific discourse if (2) above is observed.
5. The effect which a verbal analogy has on immediate comprehension of a scientific explanation is independent of the grade level for grades eight and ten except for the "SxS" format at the eighth grade level.
6. The logical form in which the scientific explanation is presented does not appear to be an important factor when verbal analogies are used in the scientific explanation to effect immediate comprehension.
7. The type of analogates employed in the primary field of a verbal analogy do not appear to affect immediate comprehension, at least for the "Advance" and "Post" formats.
8. Immediate comprehension of the scientific explanation does not seem to be affected whether or not students understand the relationships between the primary and secondary field of the verbal analogy.
9. If an understanding of the relationships between the primary and secondary field of a verbal analogy is critical to the teacher's purpose, it should be remembered that such understanding appears to be beyond the ability of most eighth grade students but within the ability of most tenth grade students.

While the results of the present study do not indicate that the use of verbal analogies in scientific explanations increases immediate comprehension of the topics employed in the study, neither are there indications that they impede immediate comprehension except in three of the seventy-three treatments. The teacher is therefore relatively free to use these types of analogies for a number of other pedagogical purposes without having to be too concerned that verbal analogies will hinder immediate comprehension. For example, it would appear to be a desirable objective of science teaching to develop an interest in students in seeking out relationships among things. Encouraging students to use analogies as in Gordon's Synectics Program (1965) may be one way to engage students in thinking about the relatedness of things. In this program of creative problem solving--often associated with "think tanks"--the familiar is made strange through setting up several kinds of analogies between the problem to be solved and some other analogical system. Through analysis of the analogical system the problem is often seen in a different light than previously and a solution to the problem can be seen. The author has found this method of problem solving very useful with high school students.

Another way that analogy may be used in the classroom is suggested by Belth (1975). Belth claims that the act of thinking is the act of analogizing. According to Belth, thinking is the act of applying a model to a given experience and using the model

as a guide to follow the experience through to its logical conclusions using the process of analogizing. In this view, if the teacher is to teach a student how to think, the teacher must instruct the student to use analogies. Furthermore, according to Belth, educating a person is to make him aware of the models he is using in his own thought processes and those which others have used to arrive at their conclusions. For example, in science the student should be given practice in the use of analogy in applying the basic models of science such as the Kinetic Molecular Theory to sense experiences. Furthermore, the student should be made aware that this theory is a basic model which scientists use in their thinking processes to conceptualize sense experiences relative to the physical nature of matter.

In general, the student should be made aware that the commonality of all disciplines lies in the act of constructing and applying models, analogies and metaphors for the general purpose of extending knowledge and understanding, and the specific purpose of adding to the knowledge and understanding of the world of things and ideas (Belth 1975:207).

A third way in which analogy may be used in the school leads to the design of a curriculum based on "integrative threads." Moses (1973:515) claims we learn by analogy. He claims that our concrete experiences become the basic analogies for first order abstractions such as concepts and theories. The first order abstractions then become the basic analogies for second order abstractions which become integrative principles for unifying knowledge. The first-order

abstractions are the products of the separate disciplines while the second-order abstractions are cross-disciplinary principles and concepts which are common to most disciplines. The second-order abstractions are the essences of our thought processes and may be used as "integrative threads" to reveal the unity of knowledge among the disciplines. These are the types of concepts Bertalanfy (1965) employed in his development of the General System Theory and that Piaget has investigated in his studies of the growth of human knowledge. They are concepts such as space, time, system, equilibrium, cycles and interaction. Concepts such as these are viewed as the "hidden analogies" or commonalities among the separate disciplines. They are concepts which have power by virtue of their general applicability. In a curriculum based on these "hidden analogies" or integrative threads the subject matter is organized in each discipline with these concepts as the focal points. In each of the subject areas the student begins with concrete realities and from these is led to first-order abstractions. These first-order abstractions are then analyzed and their essential form is abstracted by analogy to generate the second-order concepts. Jones (1969) refers to this kind of curriculum as "Logo-Learning." The function of the "integrative threads" is to supply powerful unifying centres of thought to the fractionated curriculum which exists in many of today's secondary schools. This type of curriculum organization is, at present, in operation at the Prince of Wales Mini-School in Vancouver, British Columbia.

A fourth way analogy may enter into the act of teaching is suggested by Pepper's (1966) work on world hypotheses. These world hypotheses are "root metaphors" or ways of processing information. They are the basic analogical models through which man perceives and analyzes his world. Pepper has identified four world hypotheses: formism, mechanism, contextualism and organicism. He claims that each individual tends to employ one of these four basic ways of processing information. The formist tends to perceive a stimulus in terms of the class of genetic forms to which it belongs. He concerns himself more with the overall structure rather than the parts which make the stimulus. The mechanist perceives the stimulus in terms of its discrete parts. The contextualist perceives the stimulus in terms of its context. He tends to stress the effect of external variables in his perceptual pattern. The organicist perceives the stimulus in terms of the relationships between the parts of the stimulus and between the stimulus and its surroundings. For example, consider the stimulus of a blue drinking glass placed on a red table. The formist would describe the glass in terms of classes. The glass would be perceived as a member of the class of all glass objects and all objects used for the purpose of drinking. It is a particular which is a member of many generic forms. The mechanist would describe the glass in terms of its gravitational attraction, its primary qualities of shape, weight and solidity as opposed to its secondary property of colour. The contextualist would perceive the blue glass on the red table as a situation which shapes the

glass into something it would not be if conditions were altered. If the glass were tilted or the lighting altered the "reality" of the glass would be changed. If the glass were seen through a microscope or chemically analyzed or altogether different "reality" would be perceived. In short, reality depends on context. The organicist would agree with the contextualist that the variables surrounding the glass determine its nature but he would argue for strong inter-connectedness between the variables both external and internal.

In terms of teaching, the teacher must learn to recognize which basic analogical model a student employs and initially employ that model in communicating with the student. For example, if the teachers recognize that an individual operates mainly in a mechanistic mode--that is, the student sees reality through the analogy of a machine, the teacher, in communicating with the student, could employ a mechanistic model in his teaching. In other words, the teacher may attempt to match his teaching style to the learning style of the student. After initially engaging the student through employing a "root metaphor" consonant with the learner's cognitive style, the teacher may then attempt to expand the student's outlook by leading the student through the viewpoints of others who operate using different world hypotheses. Quina (1971:316) hypothesizes that this teaching strategy would increase the probability of the following results:

1. Whatever the students interest, his range of knowing it would be extended and refined.
2. The process of interdisciplinary study--of connecting respective structures in different fields--would be enhanced.
3. Bruner's goals of transfer, retention, simplification and understanding would be enhanced.
4. The student would gain proficiency in organizing basic knowledge in terms of optional sets of categories.

The use of world hypotheses in teaching appears to offer a guideline for the individualization of instruction in terms of cognitive styles while at the same time encouraging student growth toward becoming cognitive strategists.

FURTHER RESEARCH

As a result of the present study a number of areas for further research were identified which could form the basis for further research with respect to the use of analogies in teaching. These are presented below:

1. Since the present study did not attempt any generalization to other types of analogies, the study could be replicated using;

    (a) analogies in which other types of systems are compared in the analogies. For example, the commonly used analogy between the properties of water and those of

current flow in electricity could be examined to determine whether the analogy increases comprehension, over the presentation of the theory of current flow alone,

(b) quantitative types of analogies. For example, a primary field which is ordered by a calculus could be compared with a secondary field ordered by qualitative relations to determine if the calculus becomes transferred to the secondary field,

(c) different lengths of scientific explanations. For example, a chapter of a book could be written employing an analogy and also written without the analogy to determine the effect of the analogy in comprehension of the content of the chapter.

(d) media other than the written word for presenting verbal analogies. For example, the scientific explanation and its primary field could be presented to experimental subjects via the spoken word while only the scientific explanation is presented to the control group. Then each group would respond to a test to measure immediate comprehension.

2. Research is required into what constitutes a "good" analogy for the use of analogies in teaching new learning material. For example, it has been suggested by Belth (1975) that one of the properties of a good analogy is that the primary field ought

to be derived from some observable realm. A study could be designed in which the primary field of an analogy is purely conceptual and comprehension of the resulting analogy could be compared against the comprehension of an analogy with a primary field from some observable realm.

3. In the present study the analogies employed were singular analogies composed of an entire structure of inter-related elements which were compared with the system of the secondary field . Another study could be designed to determine if it is more effective in terms of increasing comprehension to use a number of distinctly different primary fields to clarify the relations in the secondary field (i.e. multiple analogies).

4. The present study investigated only the final outcome of immediate comprehension. A similar study could be carried out in which comprehension is measured at some intermediate point to determine if the presence of an analogy in a scientific explanation functions to render learning more efficient. In other words, it may be that the use of an analogy in a scientific explanation enables the subject to reach his level of comprehension in a shorter period of time or with the expenditure of less energy. Such an effect may have the result that the student feels the subject matter is less difficult.

5. Hunt (1961) has suggested that before a child can conserve volume he must have acquired the proportionality schema. Orlando (1971) has argued that solving abstract verbal analogy problems requires the use of the proportionality schema. A study could be carried out in which performance on conservation of volume tasks is correlated with performance on an abstract verbal analogy test to give an indication as to the extent the two abilities are both dependent on the proportionality schema.

6. Research needs to be done into evaluating whether or not the use of analogy fulfills some of the other roles which are attributed to it such as:

   (a) aiding in generating hypothesis. For example, a scientific explanation could be presented alone and with an analogy and the number of hypotheses which subjects generate under the two conditions could be compared.

   (b) making subject material more interesting. A unit in science could be taught with and without analogies and an attempt could be made to measure resulting differences or changes in interest of the subjects as a result of the two treatments.

   (c) focusing the reader's attention. For example, a reading passage could be presented to subjects along with the primary field of an analogy which is designed to focus

the reader's attention on certain aspects of the passage. A test could then be designed to determine if the reader was more aware of the aspects which were focused on by the primary field than other aspects of the passage.

7. In the present study, physical analogies significantly increased immediate comprehension for what appeared to be a relatively complex argument but not for less complex argument. Argument complexity should be operationally defined and the point at which a physical analogy begins to aid comprehension should be investigated.

BIBLIOGRAPHY

Anderson, J.F. 1969. The Bond of Being. New York: Greenwood Press.

Asimov, I. 1959. "Enzymes and Metaphor," Journal of Chemical Education, 36:535.

Ausubel, D.P. 1960. "The Use of Advance Organizers in the Learning and Retention of Meaningful Verbal Material," Journal of Educational Psychology, 51:267-72.

________. 1963. The Psychology of Meaningful Verbal Learning. New York: Grune and Stratton.

________. 1965. "A Cognitive Structure View of Word and Concept Meaning," Readings in the Psychology of Cognition, Eds., D.P. Ausubel and R.C. Anderson. New York: Holt, Rinehart and Winston.

________ and D. Fitzgerald. 1961. "The Role of Discriminability in Meaningful Verbal Learning and Retention," Journal of Educational Psychology, 52:266-74.

________ and M. Youssef. 1963. "Role of Discriminability in Meaningful Parallel Learning," Journal of Educational Psychology, 54:331-36.

Beeler, N.F. 1954. "A Critical Examination of the Use of Analogy in Science Writing for Children: An Investigation of Trends in Certain Aspects of Analogy in Relation to Changes in Educational Procedures," Unpublished Ph.D. Dissertation, New York University .

Belth, M. 1975. The Processes of Thinking. Unpublished Manuscript.

Bertalanffy, L. 1968. General System Theory; Foundations, Development, Applications. New York: G. Braziller.

Bilsky, M. 1963. Patterns of Argument. New York: Holt, Rinehart and Winston.

Bloom, B.S. (Ed.). 1956. Taxonomy of Educational Objectives. New York: David McKay Company.

Bond, A.D. 1940. An Experiment in Teaching Genetics. New York: Bureau of Publications, Teachers College, Columbia University.

Brownell, W.A. and H.E. Moser. 1949. Meaningful Versus Mechanical Learning: A Study in Grade III Subtraction. Research Studies in Education No. 8. Durhan: Duke University Press.

Bruner, J.S. 1973. "Going Beyond the Information Given," Beyond the Information Given. Ed. J.M. Anglin. New York: W.W. Norton.

________, Goodnow, J.J. and G.A. Austin. 1956. A Study of Thinking. New York: John Wiley & Sons, Inc.

________. 1958. "The Role of Overlearning and Drive Level in Reversal Learning," Journal of Comparative Physiology and Phychology, 51:607-13.

Campbell, D.T. and J.C. Stanley. 1963. Experimental and Quasi-Experimental Designs for Research. Chicago: Rand McNally.

Carey, J.E. and A.E. Goss. 1957. "The Role of Mediating Verbal Responses in the Conceptual Sorting Behaviour of Children," Journal of Genetic Psychology, 90:69-74.

Carrol, J.B. 1964. "Words, Meanings and Concepts," Harvard Educational Review, 34: 178-202.

Carson, R. 1962. Silent Spring. Greenwich: Fawcett Publications.

Chemical Education Material Study. 1960. Chemistry an Experimental Science, Ed. G. Pimentel. San Francisco: W.H. Freeman and Company.

Dale, E. and J.S. Chall. 1948. "A Formula for Predicting Readability: Instructions," Educational Research Bulletin, 27:37-54.

Dienes, Z.P. 1963. An Experimental Study of Mathematical Learning. London: Hutchinson and Company Ltd.

Dowell, R.E. 1968. "The Relations Between the Use of Analogies and Their Effects on Student Achievement in Teaching a Selected Concept in High School Biology," Unpublished Ph.D. Dissertation, Indiana University.

Dreistadt, R. 1968. "An Analysis of the Use of Analogies and Metaphors in Science," Journal of Psychology, 68:97-116.

________. 1969. "Use of Analogies and Incubation in Obtaining Insights in Creative Problem Solving," Journal of Psychology, 71:159-76.

Drugge, N.L. 1968. "Atoms and Chemical Change," Developing Science Concepts in the Laboratory, Ed. N.H. Rasmussen and M.C. Schmid. Scarborough: Prentice-Hall of Canada Ltd.

Ennis, R.H. 1965. Critical Thinking Readiness in Grades One to Twelve. Phase I: Deductive Reasoning in Adolescence. Ithaca, New York: New York State College of Agriculture at Cornell University and the School of Education, Cornell University.

Ervin, S.M. 1960. "Transfer Effects of Learning a Verbal Generalization," Child Development, 31:537-54.

Fawcett, H.P. 1935. "Teaching for Transfer," Mathematics Teacher, 28:465-72.

Frase, L.T. 1968a. "Some Data Concerning the Mathemagenic Hypothesis," American Education Research Journal, 5:181-89.

________. 1968b. "Effect of Question Location, Pacing, and Mode Upon Retention of Prose Material," Journal of Educational Psychology, 59:244-49.

Frase, L.T. 1970. "Boundary Conditions for Mathemagenic Behaviours," Review of Educational Research, 40:337-47

Gates, A.I. 1935. Generalization and Transfer in Spelling. New York: Bureau of Publications, Teachers College, Columbia University.

Gendlin, E.T. 1962. Experiencing and the Creation of Meaning. New York: The Free Press of Glencoe.

Gordon, W.J.J. 1965. "The Metaphoric Way of Knowing," Education of Vision, Ed. G. Kepes. New York: George Braziller.

Grotelueschen, A. and D.D. Sjogren. 1968. "Effects of Differentially Structured Introductory Materials and Learning Tasks on Learning and Transfer," American Educational Research Journal, 5:191-201.

Guzie, T.W. 1960. The Analogy of Learning. New York: Sheed and Ward.

Haygood, R.C. and M. Stevenson. 1967. "Effects of Number of Irrelevant Dimensions in Non-Conjunctive Concept Learning," Journal of Experimental Psychology, 74:302-4.

Heidbreder, E. 1947. "The Attainment of Concepts: III The Process," Journal of Psychology, 24:93-108.

Hendrickson, G. and W.H. Schroeder. 1941. "Transfer of Training in Learning to Hit a Submerged Target," Journal of Educational Psychology, 32:205-13.

Hesse, M. 1966. Models and Analogies in Science. Notre Dame: Notre Dame University Press.

Holmquist, J.B. 1968. "A Determination of Whether the Dale-Chall Readability Formula May be Revised to Evaluate More Validly the Readability of High School Science Materials." Unpublished Ph.D. Dissertation, Colorado State University, Fort Collins.

Hovland, C.I. and W. Weiss. 1953. "Transmission of Information Concerning Concepts Through Positive and Negative Instances," Journal of Experimental Psychology, 45:175-82.

Hunt, J. McV. 1961. Intelligence and Experience. New York: The Ronald Press.

James, W. 1892. Psychology. New York: H. Holt.

Jenkins, J.J. 1966. "Meaningfulness and Concepts; Concepts and Meaningfulness," Analysis of Concept Learning, Eds. H.J. Klausmeir and C.W. Harris. New York: Academic Press.

Johnson, D.M. 1972. A Systematic Introduction to the Psychology of Thinking. New York: Harper and Row.

Jones, R. 1969. "Education for the Union of Contrasts: An Introduction to Logo-Learning," Vancouver: British Columbia Teacher's Federation. (Mimeographed).

Judd, C.H. 1902. "Practice and its Effects on the Perception of Illusions," Psychological Review, 9:27-39.

Kamenetskii, S.E. 1966. "The Use of Analogy in the Secondary School Physics Course," Translated by A. Mascona, Methods of Teaching Physics in Soviet Secondary Schools, Ed. V.F. Yus'kovich. Jerusalem, Israel Program for Scientific Translations.

Kauzman, W. 1957. Quantum Chemistry, An Introduction. New York: Academic Press Inc.

Kendler, H.H. and A.D. Karasik. 1958. "Concept Formation as a Function of Competition Between Response Produced Cues," Journal of Experimental Psychology, 55:278-83.

Langer, S.K. 1953. An Introduction to Symbolic Logic. New York: Dover Publications, Inc.

Lazslo, E. 1972. Introduction to Systems Philosophy. New York: Gordon and Breach.

Lee, D.S. 1969. "Analogy in Scientific Theory Construction," The Southern Journal of Philosophy, 7:107-25.

Lemmon, M.L. 1938. "A Psychological Consideration of Analogy," American Journal of Psychology, 51:304-56.

Liublinskaya, A.A. 1957. "The Development of Children's Speech and Thought," Psychology in the Soviet Union, Ed. S. Simon. Stanford: Stanford University Press.

Lunzer, E.A. 1970. "Problems of Formal Reasoning in Test Situations," Cognitive Development in Children: Five Monographs of the Society for Research in Child Development. Chicago: University of Chicago Press.

Martin, J. 1970. Explaining, Understanding, and Teaching. New York: McGraw-Hill.

Merril, M.D. and L.M. Stolurow. 1965. "Hierarchical Preview vs Problem Oriented Review in Learning an Imaginary Science," American Educational Research Journal, 3:251-61.

Moses, J. 1973. "Fuddled Knowledge and Befuddled Students," Teachers College Record, 74:513-28.

Nagel, E. 1961. The Structure of Science. New York: Harcourt, Brace and World.

Nuthall, G. 1968. "An Experimental Comparison of Alternative Strategies for Teaching Concepts," American Educational Research Journal, 5:561-84.

Olver, R.R. and J.R. Hornsby. 1966. "On Equivalence," Studies in Cognitive Growth, Ed. J.S. Bruner. New York: John Wiley & Sons.

Oppenheimer, R. 1956. "Analogy in Science," American Psychology, 11:127-35.

Orlando, J.E. 1971. "The Development of Analogical Reasoning Ability in Adolescent Boys," Unpublished Ph.D. Dissertation, University of Michigan.

Pepper, S.C. 1966. World Hypotheses. Berkeley: University of California Press.

Pimentel, G. (Ed.) 1960. "Chemical Education Material Study," Chemistry an Experimental Science. San Francisco: W.H. Freeman and Company.

Polanyi, M. 1962. Personal Knowledge. New York: Harper and Row.

Postman, L. 1954. Learned Principles of Organization in Memory," Psychological Monographs, 68:1-24.

Quina, J.R. 1971. "World Hypotheses: A Basis for a Structural Curriculum," Educational Theory, 21:311-19.

Reed, H.B. 1946. "Factors Influencing the Learning and Retention of Concepts: I The Influence of Set," Journal of Experimental Psychology, 36:71-8.

Rothkopf, E.Z. 1966. "Learning from Written Instructive Materials: An Exploration of the Control of Inspection Behaviour by Test-Like Events," American Educational Research Journal, 3:24-49.

Schon, D.S. 1963. Displacement of Concepts. London: Tavistock Publications.

Scott, D.D. 1964. "The Use of Analogies in Introductory College Chemistry Textbooks 1930-1960," Unpublished Ph.D. Dissertation, Peabody University.

Seward, R.K. 1966. "Relationship of Mathematical Ratios to Verbal Analogies," Unpublished Masters Thesis, University of Alberta.

Spearman, C. 1923. Nature of Intelligence. London: Macmillan.

Stein, J.J. 1952. The Effect of a Pre-Film Test on Learning from an Educational Sound Motion Picture. Technical Report-SDC.269-7-35. Pennsylvania State College, Instructional Film Research Program, November.

Swenson, E.J. 1949. "Organization and Generalization as Factors in Learning, Transfer, and Retroactive Inhibition," Learning Theory in School Situations. University of Minnesota Studies in Education, Minneapolis: University of Minnesota Press.

Talley, L.H. 1973. "The Use of Three-Dimensional Visualization as a Moderator in the Higher Cognitive Learning of Concepts in College Level Chemistry," Journal of Research in Science Teaching, 10:263-69.

Templeton, D.E. 1973. "Analogizing, Its Growth and Development," Journal of Aesthetic Education, 7:21-33.

Thiele, C.L. 1938. The Contribution of Generalization to the Learning of Addition Facts. New York: Bureau of Publications, Teachers College, Columbia University.

Turnure, C. and L. Walach. 1965. "The Influence of Contextual Variation on the Differentiation of Parts from Wholes," American Journal of Psychology, 78:481-85.

Ulmer, G. 1939. "Teaching Geometry to Cultivate Reflective Thinking: An Experimental Study with 1239 High School Pupils," Journal of Experimental Psychology, 8:18-25.

Vaihinger, H. 1924. The Philosophy of 'As If'. Translated by C.K. Ogden. New York: Harcourt Brace.

Vygotsky, L.S. 1962. Thought and Language. Translated by E. Hanfmann and G. Vakar. Cambridge: The M.I.T. Press.

Walker, C.M. and L.E. Bourne. 1961. "The Identification of Concepts as a Function of Amounts of Relevant and Irrelevant Information," American Journal of Psychology, 74:410-17.

Walter, W.G. 1953. The Living Brain. New York: Norton.

Weiss, W. and B.J. Fine. 1956. "Stimulus Familiarization as a Factor in Ideational Learning," Journal of Educational Psychology, 47:118-24.

Weller, C.M. 1970. "The Role of Analogy in Teaching Sciences," Journal of Research in Science Teaching, 7:113-19.

APPENDIX A

TREATMENTS

EXPERIMENT I

The documents related to this experiment are presented in the following order.

The first document entitled "Procedure" is the written instructions supplied to the test proctor supervising the administration of treatments.

The second document entitled "Instructions" is the test booklet instructions which appeared as the first page of each of the test booklets.

The treatments are then presented in the following order for each of the six scientific explanations:

1. Placebo -- Since the same placebo was used for all topics and argument ranks it is presented only once.
2. Postulates of the Kinetic Molecular Theory -- Since this same treatment was employed for all topics and argument ranks it is presented only once.
3. The scientific explanation employed in the "Pre," "Post", "Advance Analogy" and "Control" treatments.
4. The primary field employed in the "Pre","Post" and "Advance Analogy" treatments.

5. The concrete verbal analogy employed in the "Within" treatment.
6. The concrete verbal analogy employed in the "SxS" treatment.
7. Analogy test.
8. Criterion test.

All argument rank three treatments, analogy tests and criterion tests are presented before argument rank six treatments, analogy tests and criterion tests.

EXPERIMENT II

The scientific explanations and their corresponding criterion tests are identical to the argument rank six scientific explanations and criterion tests for Compression and Diffusion used in Experiment I; therefore, they are not presented again under Experiment II.

The scenarios employed by the researcher in presenting the demonstrations are presented under "Scenarios."

EXPERIMENT III

The test booklet containing the instructions, scientific explanation and primary field are presented.

EXPERIMENT I

PROCEDURE

Day 1

1. ADVANCED ORGANIZER DAY (2 days before test day)

Have teacher introduce you to the class.

> "I am trying to examine some different ways of presenting ideas in Science and I would like your assistance."

Hand out shuffled advance organizers. Face Down.

> "Please leave the sheets of paper face-down."

After everyone has a paper.

> "I am going to give you 4 minutes to read and study the passage on the paper. You will find that there is more than ample time. I am giving you this much time because I want you to not only read the passage, but also to study it and try to form a mental image of what is written in the passage. Mull the ideas over in your mind and I will come back to give you a test on these and some associated ideas. Begin reading now."

Give exactly four minutes. While students are reading, place 2 x 3 yellow pieces of paper on their desks. At the end of four minutes.

> "Time is up. Would you please stop reading now. While you were reading I placed a piece of paper on your desk. I would like to get the following information from you:
>
> 1. Name in full
> 2. Number of the passage you read--number is top right hand corner of sheet if there is one. If there is not a number, leave item 2 blank
> 3. Name of the passage you read."

After students finish, have student at the front of each row collect the white sheets on the way back and the yellow pieces of paper on the way forward. Then say:

> "Think about what you read over the next few days and I will come back ___(day)___ to give you a test on these ideas and some associated ones."

In preparation for the testing day, separate the yellow slips which have a number from those that do not (i.e. the "Fable for Tomorrow" ones). Attach the slips with a number to the corresponding booklet with a paper clip so they can be given out to the correct student on the day of testing. Discard the "Fable for Tomorrow" slips.

* * *

Day 2
2. TEST DAY (2 days later)

Instructions: (takes approximately 10 minutes to explain procedure)

1. Begin by having two students hand out the booklets to those students who were given the Advanced Organizer Treatment. Another student should hand out the answer sheets to every student.

2. After step 1 is complete give a girl the girl's booklets and a boy the boy's booklets and ask them to hand out the booklets to their own sex members who do not already have booklets.

3. Have another student pass out HB pencils to those who do not already have them.

4. Remind students not to open the booklets and not to write on the answer sheet yet.

5. After steps 1-4 are completed begin by filling in the answer sheet. Have students do each step as you tell them what to do. Do not entertain individual questions. Instruct the students as follows:

"If you have a question concerning something I will answer it personally after the others have started the test."

"(a) Fill in your complete name. Do not use nicknames, initials, or contractions please.

(b) Today's date is ______________.

(c) School: place the name of this school on the dotted line. Below the dotted line place the name of the elementary school you attended.

(d) Grade: place your grade and class number in this space. (Assign each class in the school a number in the order in which they are tested. If student is in grade 8 and the first class he would write 8-1). Write an example on the board.

(e) Name of Test: place the number in this space which appears in the upper right hand corner of the cover page of the test booklet.

(f) Fill in age and blacken space between the lines to indicate your sex."

INSTRUCTIONS

Passage Number _____

Indicate all your answers on the SPECIAL ANSWER SHEET provided. Use an H.B. LEAD PENCIL only. Do not use ink or ball point pens. MAKE A HEAVY BLACK MARK TO FILL THE SPACE BETWEEN THE PAIR OF LINES.

If you change your mind, erase your first mark completely.
Do not make any stray marks on the answer sheet.

BLACKEN ONE SPACE ONLY for each question.

Read the question carefully. Do not spend too much time on any one question.

EXAMPLE:

(1) All of the following are boys names except:

(a) Jim
(b) John
(c) Jane
(d) Jack
(e) Jeff

Sample Answer:

	A1	B2	C3	D4	E5
1.			■		

For each question darken the space corresponding to the word or phrase which Best answers the question or Best completes the sentence.

There is no penalty for guessing, so answer all questions.
Use PART 2 of the Answer Sheet for Analogy Test answers.
Use PART 1 of the Answer Sheet for Passage Test answers.

DO NOT MARK THIS BOOKLET IN ANY WAY.

PLEASE DO NOT TURN THIS PAGE UNTIL YOU ARE ASKED TO DO SO.

A FABLE FOR TOMORROW

There was once a town in the heart of America where all life seemed to live in harmony with its surroundings.

Then a strange blight crept over the area and everything began to change. Some evil spell had settled on the community: mysterious maladies swept the flocks of chickens, the cattle and sheep sickened and died. Everywhere was a shadow of death. The farmers spoke of much illness among their families. In the town the doctors had become more and more puzzled by new kinds of sickness appearing among their patients. There had been several sudden and unexplained deaths, not only among adults but even among children, who would be stricken suddenly while at play and die within a few hours.

There was a strange stillness. The birds, for example--where had they gone? Many people spoke of them, puzzled and disturbed. The feeding stations in the backyards were deserted. The few birds seen anywhere were moribund; they trembled violently and could not fly. It was a spring without voices; only silence lay over the fields and woods and marsh.

On the farms the hens brooded, but no chicks hatched. The farmers complained that they were unable to raise any pigs--the litters were small and the young survived only a few days. The apple trees were coming into bloom but no bees droned among the blossoms, so there was no pollination and there would be no fruit.

The roadsides, once so attractive, were now lined with browned and withered vegetation as though swept by fire. These, too were silent, deserted by all living things. Even the streams were now lifeless. Anglers no longer visited them, for all the fish had died.

In the gutters under the eaves and between the shingles of the roofs, a white granular powder still showed a few patches; some weeks before it had fallen like snow upon the roofs and the lawns, the fields and streams.

No witchcraft, no enemy action had silenced the rebirth of new life in this stricken world. The people had done it themselves.

THE KINETIC MOLECULAR THEORY

The Kinetic Molecular Theory is very helpful in explaining the physical behavior of matter. It explains: phase change; movement of molecules; properties of gases, liquids and solids; and other physical phenomena.

The Kinetic Molecular Theory is composed of five basic postulates or principles:

1. All matter is composed of very tiny individual particles called molecules. In a pure sample of matter these molecules are all identical.

2. The molecules are in constant random motion, but not all molecules, even in a pure sample, have the same speed because they are constantly colliding with each other. Some molecules are moving very rapidly, others are moving very slowly, but most molecules are moving at some speed in between these two extremes, so one speaks of the average speed of the molecules. Molecules translate energy into molecular motion; therefore, temperature gives an indication of the average speed of molecules.

3. Molecules possess energy. The energy molecules have as a result of their speed and weight is called kinetic energy. Kinetic energy is defined as one-half the weight times the square of the speed of the molecule ($KE = 1/2 \times W \times S^2$). In a pure gas not all of the molecules have the same kinetic energy because while the molecules all have the same weight, they do not have the same speed. Therefore, one must speak of the average kinetic energy of a set of molecules, just as one speaks of the average speed of the molecules. An indication of the average kinetic energy of a set of molecules is obtained by measuring the temperature.

4. There are spaces between the molecules of matter. In the gas state the average distance between the molecules is very great, whereas in the liquid and solid states the average distance between the molecules is very little.

The Kinetic Molecular Theory (continued)

5. Molecules have attractive forces among them. In the gas state these attractive forces are negligible because the average distance between molecules is very great. However, in the liquid state these forces are much stronger, and in the solid state the attractive forces are strongest.

By using any combination of some or all of these five postulates, it is possible to explain the different ways in which matter behaves physically.

PHASE CHANGE

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain phase change.

Phase change refers to the change that occurs when a solid melts, a liquid freezes or evaporates, or a gas condenses.

Consider the following reasoning concerning phase changes which take place in a tightly sealed jar which is three-quarters full of a liquid at room temperature and is heat insulated from the surroundings.

If the temperature of the liquid in the jar is increased, then the average speed of the molecules of the liquid increases. If the speed of the molecules of the liquid increases, then more molecules have enough speed to escape from the surface of the liquid or evaporate. If this happens, then there will be a greater number of molecules of vapour in the restricted space above the liquid.

Therefore, if the temperature of the liquid in the jar is increased, then there are a greater number of molecules of vapour in the restricted space above the liquid.

Go on to the next page

PHASE CHANGE ANALOGY - A COMPARISON

One can explain evaporation and condensation of a liquid by comparing molecules to people at a school dance.

The jar may be thought of as the dance hall building. Think of the bystanders around the edge of the dance floor as being molecules in the liquid phase, and of the people actually dancing as molecules in the vapour phase. The dancers are dancing a rather slow number.

If the tempo of the music increases, more couples form and move out from the sidelines, just as when the temperature is raised, more molecules evaporate from the liquid.

If more couples "evaporate", there are a greater number of people dancing on the area of the floor restricted to dancers.

Therefore, as the tempo of the music increases, the number of people dancing increases.

Go on to the next page

PHASE CHANGE

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain phase change.

Phase change refers to the change that occurs when a solid melts, a liquid freezes or evaporates, or a gas condenses.

One can explain evaporation and condensation of a liquid by comparing molecules to people at a school dance.

Consider the following reasoning concerning phase changes which take place in a tightly sealed jar which is three-quarters full of a liquid at room temperature and is heat insulated from the surroundings.

The jar may be thought of as the dance hall building. Think of the bystanders around the edge of the dance floor as being molecules in the liquid phase, and of the people actually dancing as molecules in the vapour phase. The dancers are dancing a rather slow number.

If the temperature of the liquid in the jar is increased, then the average speed of the molecules of the liquid increases. If the speed of the molecules of the liquid increases, then more molecules have enough speed to escape from the surface of the liquid or evaporate. If this happens, then there will be a greater number of molecules of vapour in the restricted space above the liquid.

If the tempo of the music increases, more couples form and move out from the sidelines, just as when the temperature is raised, more molecules evaporate from the liquid.

If more couples "evaporate," there are a greater number of people dancing on the area of the floor restricted to dancers.

Therefore, if the temperature of the liquid in the jar is increased, then there are a greater number of molecules of vapour in the restricted space above the liquid.

Therefore, as the tempo of the music increases, the number of people dancing increases.

Go on to the next page

PHASE CHANGE

Passage	Comparison (Analogy)
The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain phase change.	One can explain evaporation and condensation of a liquid by comparing molecules to people at a school dance.
Phase change refers to the change that occurs when a solid melts, a liquid freezes or evaporates, or a gas condenses. Consider the following reasoning concerning phase changes which take place in a tightly sealed jar which is three-quarters full of a liquid at room temperature and is heat insulated from the surroundings.	The jar may be thought of as the dance hall building. Think of the bystanders around the edge of the dance floor as being molecules in the liquid phase, and of the people actually dancing as molecules in the vapour phase. The dancers are dancing a rather slow number.
If the temperature of the liquid in the jar is increased, then the average speed of the molecules of the liquid increases. If the speed of the molecules of the liquid increases, then more molecules have enough speed to escape from the surface of the liquid or evaporate. If this happens, then there will be a greater number of molecules of vapour in the restricted space above the liquid.	If the tempo of the music increases, more couples form and move out from the sidelines, just as when the temperature is raised, more molecules evaporate from the liquid. If more couples "evaporate," there are a greater number of people dancing on the area of the floor restricted to dancers.
Therefore, if the temperature of the liquid in the jar is increased, then there are a greater number of molecules of vapour in the restricted space above the liquid.	Therefore, as the tempo of the music increases, the number of people dancing increases.

Go on to the next page

PHASE CHANGE ANALOGY TEST

1. Good is to bad as light is to:
   (a) bulb
   (b) dark
   (c) evil
   (d) angelic
   (e) white

2. Jane is to John as girl is to:
   (a) lady
   (b) Miss
   (c) boy
   (d) woman
   (e) Mister

3. Molecules are to temperature as people at a school dance are to:
   (a) evaporation
   (b) the dance floor
   (c) the tempo of the music
   (d) compression
   (e) intermolecular forces

4. People dancing on the floor are to people standing along the side-lines as molecules in the gas phase are to:
   (a) faster moving molecules
   (b) the average kinetic energy of molecules
   (c) the average speed of the molecules
   (d) molecules in the liquid phase
   (e) molecules evaporating

Go on to the next page

5. The jar is to the entire dance hall as the vapour in the jar is to the:

   (a) people along the sidelines
   (b) people dancing on the floor
   (c) people in the band
   (d) movement of people dancing
   (e) rate of movement of people along the sidelines

6. People dancing are to couples forming and beginning to dance as molecules in the vapour are to:

   (a) molecules in the liquid
   (b) molecules evaporating from the liquid
   (c) molecules condensing from the gas
   (d) people along the sidelines
   (e) faster moving molecules

7. The rate of movement of people dancing is to the tempo of the music as the average speed of the molecules is to the:

   (a) pressure
   (b) temperature
   (c) volume
   (d) number of molecules
   (e) number of people

8. An increase in temperature of the liquid is to an increase in the number of molecules in the vapour as an increase in the tempo of the music is to:

   (a) a greater number of people dancing
   (b) a greater number of people along the sidelines
   (c) a greater number of couples forming
   (d) the average speed of the molecules
   (e) all the couples in the dance hall

Go on to the next page

PHASE CHANGE TEST

1. The initial conditions under which the reasoning in the passage began were:
   - (a) an open jar 3/4 full of liquid at room temperature and insulated from its surroundings
   - (b) a tightly sealed jar 3/4 full of liquid at room temperature insulated from its surroundings
   - (c) a jar full of vapour at room temperature insulated from its surroundings
   - (d) a jar 3/4 full of liquid and not at room temperature, but insulated from its surroundings
   - (e) a jar 3/4 full of liquid at room temperature and insulated from its surroundings

2. When the temperature of the liquid was raised:
   - (a) the average speed of the molecules remains the same because an average cannot change
   - (b) the average speed of the molecules decreased because there was more evaporation
   - (c) the average speed of the molecules increased because hotter molecules are lighter
   - (d) the average speed of the molecules increased because temperature gives an indication of the average speed of the molecules
   - (e) the average speed of the molecules decreased because the temperature is a measure of the average kinetic energy of the molecules

3. The reason why the number of molecules in the vapour increased when the temperature of the liquid increased was that:
   - (a) the rate of evaporation increased
   - (b) the Kinetic Molecular Theory of Matter explains the behaviour of the liquid
   - (c) there are attractive forces between molecules in the liquid
   - (d) there are larger average spaces between the molecules in the gas phase
   - (e) the temperature is an indication of the average speed of the molecules

Go on to the next page

4. Which of the following statements follows directly from the reasoning used in the passage?

    (a) The temperature of a liquid determines its boiling point

    (b) The average molecular speed of the molecules in the liquid determines the number of molecules in the vapour

    (c) If two samples of liquid contain the same amount of heat, then they will be at the same temperature

    (d) The vapour above the liquid will be at a higher temperature than the liquid in the jar

    (e) The same amount of heat is required to vaporize a certain number of molecules regardless of what liquid is used

5. The rate of evaporation of a liquid can be increased by:

    (a) decreasing the average kinetic energy of the molecules of the liquid

    (b) increasing the pressure on the liquid

    (c) increasing the number of molecules of liquid

    (d) decreasing the space above the liquid

    (e) increasing the temperature of the liquid

6. If the number of molecules decreased in the vapour space described in the passage, then:

    (a) the speed of the molecules in the liquid must have increased

    (b) the rate of evaporation must have increased

    (c) the temperature of the liquid in the jar must have decreased

    (d) the temperature of the molecules in the vapour must have increased

    (e) the size of the molecules in the vapour must have increased

Go on to the next page

7. A bottle of liquid is completely heat insulated from its surroundings and some of the liquid is allowed to evaporate. The evaporated molecules are removed immediately from the vicinity of the liquid. The temperature of the liquid in the bottle would:

   (a) increase

   (b) decrease

   (c) remain the same

   (d) not be predictable

   (e) increase and then decrease

8. Assume there are two identical SEALED bottles A and B containing the same amounts of the same liquid. There are twice as many molecules in the vapour above the liquid in bottle A as there are in bottle B. Which of the following statements best describes the above system?

   (a) The temperature of the liquid in bottle A is lower than the temperature of the liquid in bottle B

   (b) The average speed of the molecules in bottle A is less than the average speed of the molecules in bottle B

   (c) The two bottles could not contain the same liquid

   (d) The pressure in bottle A was less than the pressure in bottle B

   (e) The temperature of the liquid in bottle A is higher than the temperature of the liquid in bottle B

9. The average speed at which molecules move can be changed by:

   (a) changing the number of molecules

   (b) changing the potential energy of the molecules

   (c) changing the rate at which the molecules condense

   (d) changing the temperature of the molecules

   (e) changing the pressure on the molecules if the temperature is constant

10. The temperature of a substance is determined by the:

   (a) weight of a molecule of the substance

   (b) number of molecules or atoms

   (c) total weight of molecules or atoms

   (d) speed and number of molecules

   (e) average speed of its molecules

Go on to the next page

11. Which of the following decreases the evaporation rate of a liquid in an open container

    (a) Raise the temperature of the liquid

    (b) Make the surface area of the liquid larger

    (c) Increase the average kinetic energy of the molecules

    (d) Decrease the average speed of the molecules

    (e) None of the above

12. If one wanted to get an indirect measure of the average speed of molecules of a substance one would use a/an:

    (a) ammeter

    (b) spectrometer

    (c) odometer

    (d) thermometer

    (e) barometer

13. Suppose there is a machine to separate molecules which have speeds greater than the average speed from those that move at a speed less than the average speed. The molecules with speeds less than the average speed would:

    (a) feel warmer than the molecules with speeds greater than the average speed

    (b) evaporate more slowly than the molecules with speeds greater than the average

    (c) have less heat, but more energy than the molecules with speeds greater than the average speed

    (d) have more heat but less energy than the molecules with speeds greater than the average speed

    (e) have more heat and more energy than the molecules with speeds greater than the average speed

14. Assume that you have a glass of water whose molecules have a certain average speed. A number of water molecules which had a greater average speed than the average speed of the water molecules in the glass were added to the water in the glass. Which of the following statements correctly describes the change which would occur?

    (a) The temperature of the water in the glass would decrease

Go on to the next page

(b) The molecules added to the glass would speed up

(c) The temperature of the molecules added to the water in the glass would increase

(d) The temperature of the water in the glass would increase

(e) The average kinetic energy of the molecules in the glass would decrease

15. Assume that you have two identical sealed Jars A and B filled to the same level with the SAME liquid. It was determined that the average speed of the molecules in Jar A was greater than the average speed of the molecules in Jar B. Which of the following statements concerning these two jars is correct?

(a) The number of molecules in the vapour above the liquid in Jar A is less than the number in the vapour of Jar B

(b) The vapour above the liquid in Jar B is hotter than the vapour in Jar A

(c) The molecules of liquid in Jar A must be lighter than the molecules of liquid in Jar B

(d) The number of molecules in the vapour above the liquid in Jar A is greater than the number in the vapour of Jar B

(e) None of these statements is correct

16. The over-all conclusion in this passage was:

(a) Temperature is a measure of the average speed of molecules

(b) Molecules in the vapour are farther apart than molecules in the liquid

(c) An increase in temperature results in an increase in the amount of vapour above the liquid

(d) Evaporation of molecules is a cooling process

(e) Whenever more heat is supplied to the system, more molecules will evaporate

STOP: Do not turn this page until you are asked to do so. If you are finished before time is called, check your work.

COMPRESSION

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas compression.

Gas compression refers to decreasing the volume by increasing the pressure on a fixed amount of gas in a container.

Consider the following reasoning concerning the compression of a gas by a piston at a constant temperature which is below a particular temperature specific to each gas.

If the gas is compressed continuously at constant temperature, then the molecules of the gas move closer and closer together. If the molecules move closer and closer together, then the attractive forces among the molecules get stronger and stronger. If this happens, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

Therefore, if the gas is compressed continuously at constant temperature, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

Go on to the next page

COMPRESSION ANALOGY - A COMPARISON

The compression of a gas can be explained by comparing molecules of the gas to people.

Consider what happens to people when they are "pushed" closer together as they are in moving from the country into the city.

If people are "pushed"closer and closer together as they are when they live closer and closer together, then attractive forces among the people increase, just as they do among molecules when they are pushed closer together.

As people get to know each other well, the attractive forces increase and small informal groups of people such as friendship groups or "gangs" are formed. These informal groups compare to the small clusters of molecules.

Therefore, as people are brought closer together, small informal groups begin to form.

Go on to the next page

COMPRESSION

The following paragraphs illustrate how the Kinetic Molecular theory can be used to explain gas compression.

Gas compression refers to decreasing the volume by increasing the pressure on a fixed amount of gas in a container.

The compression of a gas can be explained by comparing molecules of the gas to people.

Consider the following reasoning concerning the compression of a gas in a piston at a constant temperature which is below a particular temperature specific to each gas.

Consider what happens to people when they are "pushed" closer and closer together as they are in moving from the country into the city.

If the gas is compressed continuously at constant temperature, then the molecules of the gas move closer and closer together. If the molecules move closer and closer together, then the attractive forces among the molecules get stronger and stronger.

If people are "pushed" closer and closer together as they are when they live closer and closer together, then attractive forces among the people increase, just as they do among molecules when they are pushed closer together.

If this happens, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

As people get to know each other well, the attractive forces increase and small informal groups of people such as friendship groups or "gangs" are formed. These informal groups compare to the small clusters of molecules.

Therefore, if the gas is compressed continuously at constant temperature, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

Therefore, as people are brought closer together, small informal groups begin to form.

Go on to the next page

COMPRESSION

Passage	Comparison (Analogy)
The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas compression.	The compression of a gas can be explained by comparing molecules of the gas to people.
Gas compression refers to decreasing the volume by increasing the pressure on a fixed amount of gas in a container.	Consider what happens to people when they are "pushed" closer together as they are in moving from the country into the city.
Consider the following reasoning concerning the compression of a gas in a piston at a constant temperature which is below a particular temperature specific to each gas.	
If the gas is compressed continuously at constant temperature, then the molecules of the gas move closer and closer together If the molecules move closer and closer together, then the attractive forces among the molecules get stronger and stronger.	If people are "pushed" closer and closer together as they are when they live closer and closer together, then attractive forces among the people increase, just as they do among molecules when they are pushed closer together.
If this happens, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.	As people get to know each other well, the attractive forces increase and small informal groups of people such as friendship groups or "gangs" are formed. These informal groups compare to the small clusters of molecules.

Go on to the next page

Compression (continued)

Passage	Comparison (Analogy)
Therefore, if the gas is compressed continuously at constant temperature, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.	Therefore, as people are brought closer together, small informal groups begin to form.

Go on to the next page

COMPRESSION ANALOGIES TEST

1. Good is to bad as light is to:
   (a) bulb
   (b) dark
   (c) evil
   (d) angelic
   (e) white

2. Jane is to John as girl is to:
   (a) lady
   (b) Miss
   (c) boy
   (d) woman
   (e) Mister

3. People are to attractive forces among people as molecules are to:
   (a) repulsive forces among molecules
   (b) the temperature of the gas
   (c) repulsive forces among people
   (d) attractive forces among molecules
   (e) the pressure of the gas

4. Molecules in a gas at room pressure are to molecules in a compressed gas as people who live far apart are to:
   (a) molecules
   (b) people who move very quickly
   (c) weak attractive forces
   (d) strong attractive forces
   (e) people who live close together

5. Groups of people are to groups of molecules as friendship is to:
   (a) love
   (b) hatred
   (c) attractive forces
   (d) repulsive forces
   (e) cities

Go on to the next page

Compression Analogies Test (continued)

6. Compression of a gas is to molecular clusters as people living in cities are to:
   (a) people living in the country
   (b) people moving more slowly
   (c) attractive forces
   (d) gangs
   (e) love

7. People who live close together are to friendship as molecules which are far apart are to:
   (a) heating of a gas
   (b) weak attractive forces
   (c) compression of a gas
   (d) strong attractive forces
   (e) love

8. Compression of a gas is to expansion of a gas as people moving from the country to the city are to:
   (a) strong attractive forces
   (b) weaker attractive forces
   (c) people moving from the city to the country
   (d) molecules moving closer together
   (e) molecules moving farther apart

Go on to the next page

COMPRESSION TEST

1. The stated conditions under which the reasoning in the passage holds were:

   (a) The gas is compressed continuously at constant pressure which is below a particular temperature specific to each gas

   (b) The gas is compressed continuously at a constant temperature which is below a particular temperature specific to the gas

   (c) Gases which have intermolecular forces are compressed

   (d) The compressed gas is assumed to have no inter-molecular forces, but must be below a specific temperature during compression

   (e) The gas is compressed continuously at a particular temperature specific to the gas

2. When the molecules are close to each other:

   (a) the repulsive forces become weaker

   (b) the effect of the attractive forces among molecules becomes less noticeable

   (c) the molecules become smaller

   (d) the attractive forces among the molecules are dependent on the temperature

   (e) the attractive forces become stronger

3. The reason why the molecules began to group together to form clusters is that:

   (a) the temperature was held constant during the compression

   (b) the attractive forces concentrated more and more in the molecules as they became smaller and smaller

   (c) the average speed of the molecules decreased

   (d) the attractive forces among the molecules became stronger when the molecules were pushed closer together

   (e) the molecules began to form clusters because they were cooler

4. Which one of the following statements follows directly from the reasoning used in the passage?

   (a) If a gas has no intermolecular forces, it would not condense when compressed

Go on to the next page

Compression Test (continued)

(b) A gas condenses when compressed because compression cools the gas

(c) A liquid occupies less volume than a gas because the molecules of a liquid are smaller than those of the gas due to compression.

(d) The molecules in a compressed gas move faster even though the gas is held at constant temperature

(e) A gas which has intermolecular forces will ultimately condense when compressed no matter what the temperature of the gas is as long as the temperature is held constant

5. When the volume of a certain amount of gas is decreased, the:

   (a) temperature decreases

   (b) molecules decrease in size

   (c) molecules decrease in size; therefore, the attractive forces among molecules increase

   (d) weight of the molecules decreases

   (e) attractive forces among the molecules increase

6. When gases are compressed at constant temperature, the molecules begin to form clusters when the:

   (a) molecules slow down enough

   (b) average kinetic energy decreases enough

   (c) molecules are close enough

   (d) molecules become small enough

   (e) volume is increased enough

7. While a gas is being compressed the:

   (a) molecules become smaller

   (b) attractive forces increase

   (c) temperature of the gas decreases

   (d) kinetic energy of the molecules decreases

   (e) molecular speed decreases

Go on to the next page

Compression Test (continued)

Use the Information below to answer Questions 8 to 10 inclusive.

The two balloons were blown up with air so that they had identical volumes when they were at room pressure. They were then inserted into the jars which were stoppered. The pressures of the air inside the jars were changed so that the balloon in Jar A became much larger than the balloon in Jar B as shown in the diagram. The temperature of the jars and contents were the same in both cases.

8. One can conclude that the air pressure:

   (a) is greater in Jar A than in Jar B
   (b) is greater in the balloon in Jar A than it is in the balloon in Jar B
   (c) is less in Jar A than in Jar B
   (d) is the same in the balloon in Jar A as it is in the balloon in Jar B
   (e) is greater in Jar A than in the balloon in Jar A

9. One can conclude that the strength of the attractive forces among the molecules after the pressure was changed:

   (a) is greater in the balloon in Jar A than in the baloon in Jar B
   (b) is the same in the balloon in Jar A as in the balloon in Jar B
   (c) is greater in Jar A than in Jar B
   (d) is less in Jar A than in Jar B
   (e) is greater in Jar B than in the balloon in Jar B

10. Which molecules would be the nearest to forming clusters of molecules?

   (a) The gas molecules inside Jar A
   (b) The gas molecules inside the balloon of Jar A
   (c) The gas molecules inside the balloon of Jar B
   (d) The gas molecules inside Jar B
   (e) None of the above

Go on to the next page

Compression Test (continued)

11. If a gas were allowed to expand at constant temperature:
    - (a) the molecules would become larger
    - (b) the intermolecular forces of the gas would increase
    - (c) the molecules would move farther apart
    - (d) the kinetic energy of the molecules would increase
    - (e) the distance between the molecules would decrease

12. Equal volumes of gaseous water and gaseous ammonia were placed into two cylinders at the same temperature. The two gases were both compressed to equal volumes and the water molecules began to form clusters whereas the ammonia did not. The temperature was kept the same in both cylinders throughout the compression. One may conclude from these observations that:
    - (a) gaseous water is easier to compress than gaseous ammonia
    - (b) the attractive forces among the water molecules are stronger than those among the ammonia molecules
    - (c) the water molecules had greater kinetic energy than the ammonia molecules
    - (d) the attractive forces among the water molecules are weak in comparison to those among the ammonia molecules
    - (e) the water molecules have a greater average speed than the ammonia molecules.

13. If you had a sample of liquid water molecules and a sample of gaseous water molecules, you could conclude:
    - (a) the gaseous water molecules were at a higher temperature than the liquid water molecules
    - (b) the gaseous water molecules are at the same temperature as the liquid water molecules
    - (c) the attractive forces among the molecules in the liquid are stronger than those among the molecules in the gas
    - (d) the molecules in the gas are larger than those in the liquid
    - (e) the two samples must be under different pressures

Go on to the next page

Compression Test (continued)

14. Since each known substance on the earth can exist as a gas, a liquid, and a solid, we may conclude:

    (a) no substance can get any colder than its freezing temperature

    (b) the Kinetic Molecular Theory is a perfect theory

    (c) all gases can be turned to liquids simply by compressing them

    (d) there can only be three states of matter

    (e) all molecules must have attractive forces for each other

15. Consider two cylinders containing equal numbers of molecules of gases X and Y. Both gases are at the same temperature. The molecules of gas X are a greater average distance apart than the molecules of gas Y. Which of the following statements is a conclusion which follows from this information?

    (a) The molecules in gas Y have weaker attractive forces among them than the molecules of gas X

    (b) The average kinetic energy of gas X molecules is greater than that of gas Y molecules

    (c) The volume of the cylinder containing gas X is smaller than volume of the cylinder containing gas Y

    (d) The pressure on the cylinder containing gas Y is greater than the pressure on the cylinder containing gas X

    (e) The average kinetic energy of gas X molecules is less than that of gas Y molecules

16. The over-all conclusion in the passage was:

    (a) By compressing the gas continuously at constant temperature, the gas molecules begin to cluster together

    (b) By compressing the gas continuously, the molecules of the gas become smaller and therefore, have stronger attractive forces because they become concentrated

    (c) Compressing a gas increases the attractive forces among molecules of the gas

    (d) When gases are compressed, the temperature of the gas remains constant

    (e) The closer molecules are to each other, the stronger are the attractive forces among them.

STOP: Do not turn this page until you are asked to do so. If you are finished before time is called, check your work.

DIFFUSION

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas diffusion.

Gas diffusion refers to the spontaneous mixing of two or more gases when they are placed in contact with each other.

Consider the following reasonong concerning the diffusion through air contained in a pipe of a mixture of equal amounts of pure gases whose molecules have very different weights.

If the temperature of the two gases in the mixture is the same, then the molecules of the gases have the same kinetic energy. If the molecules have the same kinetic energy, then the lighter molecules have greater average speed than the heavier molecules. If this happens, the lighter gas molecules travel their zig-zag course or diffuse faster among the air molecules in the pipe than the heavier gas molecules.

Therefore, if the temperatures of the two gases in the mixture are equal, the lighter gas traverses or diffuses faster among the air molecules in the pipe than the heavier gas.

Go on to the next page

DIFFUSION ANALOGY - A COMPARISON

Gas diffusion can be explained by comparing molecules of a gas to a group of students mixing with the crowd after entering a busy fairground.

Assume that half the students weigh 100 pounds and that the other half weigh 250 pounds. Furthermore, assume that all students have equal strength, just as both gases in the mixture have the same temperature.

If all students have the same strength, they will all have the same average kinetic energy because while the 100 pound students are lighter, their average speed will be greater as they move among the people at the fair. If their average speed is greater, the leading light students will travel farther in the same amount of time along the fairground than the leading heavier students. This is comparable to light gas molecules diffusing faster than the heavy gas molecules.

Go on to the next page

DIFFUSION

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas diffusion.

Gas diffusion refers to the spontaneous mixing of two or more gases when they are placed in contact with each other.

Gas diffusion can be explained by comparing molecules of a gas to a group of students mixing with the crowd after entering a busy fairground.

Consider the following reasoning concerning the diffusion through air contained in a pipe of a mixture of equal amounts of two pure gases whose molecules have very different weights.

Assume that half the students weigh 100 pounds and that the other half weigh 250 pounds. Furthermore, assume that all students have equal strength, just as both gases in the mixture have the same temperature.

If the temperature of the two gases in the mixture is the same, then the molecules of the gases have the same kinetic energy. If the molecules have the same kinetic energy, then the lighter molecules have greater average speed than the heavier molecules. If this happens, the lighter gas molecules travel their zig-zag course or diffuse faster among the air molecules in the pipe than the heavier gas molecules.

If all students have the same strength, they will all have the same kinetic energy because while the 100 pound students are lighter, their average speed will be greater as they move among the people at the fair. If their average speed is greater, the leading light students will travel farther in the same amount of time along the fairground than the leading heavier students.

Therefore, if the temperatures of the two gases in the mixture are equal, the lighter gas traverses or diffuses faster among the air molecules in the pipe than the heavier gas.

This is comparable to light gas molecules diffusing faster than the heavy molecules.

Go on to the next page

DIFFUSION

Passage	Comparison (Analogy)
The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas diffusion.	Gas diffusion can be explained by comparing molecules of a gas to a group of students mixing with the crowd after entering a busy fairground.
Gas diffusion refers to the spontaneous mixing of two or more gases when they are placed in contact with each other.	Assume that half the students weigh 100 pounds and that the other half weigh 250 pounds. Furthermore, assume that all students have equal strength, just as both gases in the mixture have the same temperature.
Consider the following reasoning concerning the diffusion through air contained in a pipe of a mixture of equal amounts of two pure gases whose molecules have very different weights.	
If the temperature of the two gases in the mixture is the same, then the molecules of the gases have the same kinetic energy. If the molecules have the same kinetic energy, then the lighter molecules have greater average speed than the heavier molecules. If this happens, the lighter gas molecules travel their zig-zag course or diffuse faster among the air molecules in the pipe than the heavier gas molecules.	If all students have the same strength, they will all have the same kinetic energy because while the 100 pound students are lighter, their average speed will be greater as they move among the people at the fair. If their average speed is greater, the leading light students will travel farther in the same amount of time along the fairground than the leading heavier students. This is comparable to light gas molecules diffusing faster than the heavy gas molecules.
Therefore, if the temperatures of the two gases in the mixture are equal, the lighter gas traverses or diffuses faster among the air molecules in the pipe than the heavier gas.	

Go on to the next page.

DIFFUSION ANALOGY TEST

1. Good is to bad as light is to:
   - (a) bulb
   - (b) dark
   - (c) evil
   - (d) angelic
   - (e) white
2. Jane is to John as girl is to:
   - (a) lady
   - (b) Miss
   - (c) boy
   - (d) woman
   - (e) Mister
3. The original group of students is to their movement among the people at the fair as the gas molecules in the mixture are to:
   - (a) temperature
   - (b) pressure
   - (c) air molecules
   - (d) diffusion through air
   - (e) speed of the molecules of the mixture
4. The 100 pound and 250 pound students are to their equal strength as the molecules of the two gases in the mixture are to:
   - (a) their equal average volumes
   - (b) their equal average speeds
   - (c) their equal temperature
   - (d) their equal average numbers of molecules
   - (e) their equal average potential energies
5. The average speed of the 100 pound students is to the average molecular speed of the lighter gas molecules as the average speed of the 250 pound students is to:
   - (a) the average kinetic energy of the heavier gas molecules
   - (b) the average temperature of the heavier gas molecules
   - (c) the average temperature of the lighter gas molecules
   - (d) the average pressure of the heavier gas molecules
   - (e) the average molecular speed of the heavier gas molecules

Go on to the next page

6. The molecules in the mixture of gases are to the air molecules as the students are to:
   (a) the speed of the students
   (b) the people at the fair
   (c) the strength and stamina of the students
   (d) the temperature of the air
   (e) the length of the students' legs

7. The students are to the fairground as the molecules of the mixture are to:
   (a) the heavy molecules
   (b) the light molecules
   (c) the pipe
   (d) air molecules
   (e) the obstacles

8. The equal kinetic energy of the students is to their equal strength as the equal kinetic energy of the molecules is to:
   (a) their equal molecular size
   (b) their equal temperature
   (c) their equal volumes
   (d) their equal numbers of molecules
   (e) their equal pressures

Go on to the next page

DIFFUSION TEST

1. The stated conditions under which the reasoning in the passage holds were:
   - (a) The mixture of the two pure gases whose molecules have different molecular weights was allowed to diffuse through a vacuum
   - (b) The two pure gases were not at the same temperature originally
   - (c) The mixture of two gases whose molecules have different molecular weights was allowed to diffuse through air
   - (d) The mixture of two pure gases was separated into the separate gases before they were allowed to diffuse through air
   - (e) The mixture of two pure gases whose molecules had the same weights was allowed to diffuse through air

2. Which of the following statements about the two gases in the passage is correct?
   - (a) The molecules of the lighter gas move faster because the lighter molecules have more kinetic energy than the heavier molecules
   - (b) The molecules of the lighter gas move faster because they are at a higher temperature than the molecules of the heavier gas
   - (c) The molecules of the lighter gas move faster than the molecules of the heavier since the light and heavy molecules have the same average kinetic energy
   - (d) If the temperature of both gases was increased, the molecules of the heavier gas will then move as fast as the molecules of the lighter gas
   - (e) The two gases would move at the same speed if they were at the same temperature

3. The lighter gas diffuses faster than the heavier gas because:
   - (a) The lighter gas molecules have a greater average speed than the heavier gas molecules
   - (b) The Kinetic Molecular Theory of Matter indicates that the difference in rates of diffusion of gases is caused by a difference in molecular volume.
   - (c) The attractive forces among the molecules of the heavier gas are greater than the attractive forces among the molecules of the lighter gas

Go on to the next page

Diffusion Test (continued)

(d) The heavier gas molecules, being bigger, have more momentum

(e) The attractive forces among the molecules of the heavier gas are less than the attractive forces among the molecules of the lighter gas

4. Which one of the following statements follows directly from the reasoning used in the passage?

(a) Two gases which have molecules which weigh the same would have the same temperature

(b) The kinetic energy of the light gas molecules is different from the kinetic energy of the heavy gas molecules

(c) The gas having the slowest rate of diffusion will arrive at a certain point after the gas having a faster rate of diffusion

(d) Molecules move faster when they diffuse through air than do the air molecules

(e) When considering diffusion of a gas through air, the air molecules are assumed to be motionless

5. Since the two gases had the same temperature, they had the same:

(a) molecular volume

(b) average kinetic energy

(c) amount of heat

(d) average speed of molecules

(e) average distance between the molecules.

Questions 6 and 7 refer to the following situation. A student uncorks two identical bottles in a still room (no air currents). Each bottle contains a different gas, but both gases are at the same temperature. He places the uncorked bottles beside each other and sits down about six feet away from them. He smells the odour of gas A before the odour of gas B.

Go on to the next page

Diffusion Test (continued)

6. Which of the following statements concerning the gases is correct?
   (a) Gas A travels through air by the process of diffusion slower than gas B
   (b) Gas A diffuses at a faster rate than gas B
   (c) Gas B has a greater average molecular speed than gas A
   (d) The average kinetic energy of gas A molecules is greater than the average kinetic energy of gas B molecules
   (e) Since the molecules of gas A are lighter than the molecules of gas B, gas B molecules will diffuse faster

7. Which statement about the molecules of the gases is correct?
   (a) The average kinetic energy of the molecules of gas A is greater than the average kinetic energy of the molecules of gas B
   (b) The average speed of the molecules of both gases is the same
   (c) The average speed of the gas molecules will be greater than the average speed of the air molecules
   (d) The average speed of the molecules of gas A is greater than the average speed of the molecules of gas B
   (e) The average speed of the gas molecules will be less than the average speed of the air molecules

Go on to the next page

Diffusion Test (continued)

Questions 8 to 13 inclusive refer to the following diagram:

Initially the hypodermic syringe on the left contains gas A and the syringe on the right contains gas B. Both gases are at the same temperature. The glass tube is filled with air in which there are no air currents. It is known that when gas A and B meet they react chemically to form a white smoke. Gases A and B are different gases in each of the following experiments.

8. In the first experiment, a small amount of each of the gases is injected into the tube at the same time. After a period of time a smoke is observed in region 1. This indicates:
   - (a) The molecular weight of gas A is less than the molecular weight of gas B
   - (b) The average kinetic energy of gas A molecules is greater than the average kinetic energy of gas B molecules
   - (c) The molecular weight of gas A is greater than the molecular weight of air
   - (d) The weight of the molecules of gas A is greater than the weight of the molecules of gas B
   - (e) The average kinetic energy of gas A molecules is less than the average kinetic energy of gas B molecules

9. In the second experiment, the smoke is first observed in region 2 after a small amount of each of the gases (not the same two as in question 8) was injected into the tube at the same time. From this observation one could conclude:
   - (a) The rates of diffusion of the two gases must be equal
   - (b) The potential energies of the two gases must be equal
   - (c) If it were not known that the temperatures of the two gases A and B were equal, this would indicate that the temperatures were equal

Diffusion Test (continued)

(d) The molecular weight of gas A is greater than the molecular weight of gas B

(e) The gases in hypodermic syringes A and B would have to be the same gas

10. In a third experiment it was noted that when gases A and B were at the same temperature, initially the smoke formed in region 3. If gas B was heated to a temperature above the temperature of gas A, in what region would you observe the formation of smoke?

    (a) To the right of region 3

    (b) To the left of region 3

    (c) In region 3

    (d) In region 1

    (e) In region 2

11. In a fourth experiment, two gases A and B were injected. A white smoke was first observed in region 3. Then the two were replaced by two chemicals X and Y which had identical molecular weights to gases A and B, respectively. The air in the glass tube was replaced with water. The experiment was then repeated by injecting the chemicals S and Y into the water. When the two chemicals met, a white solid was formed. The results of the two experiments were compared. Using your knowledge about the diffusion process, which of the following predictions is a correct one?

    (a) You cannot make any predictions because the experiments are not comparable

    (b) The white solid would form to the right of region 3

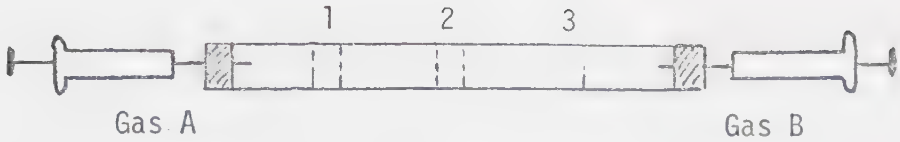
    (c) The white solid would form to the left of region 3

    (d) The white solid would form in region 3, but it would take much longer to form than in the case of the white smoke formation

    (e) The white solid would form in region 3, but it would not take nearly as long as it did for the white smoke to form

Go on to the next page

Diffusion Test (continued)



12. In a fifth experiment, with the glass tube again filled with air, the two gases A and B were injected at the same time and allowed to stand for some considerable period of time after the smoke was first observed in region 3. Smoke was then observed over the entire length of the tube. This is an example of:

    (a) air currents

    (b) convection

    (c) expansion

    (d) diffusion

    (e) condensation

13. In a sixth experiment gases A and B were injected into the tube filled with air. It was noted that it took ten minutes for the smoke to appear in region 3. Then all of the air was removed from the tube and the two gases were injected. The entire tube filled with white smoke immediately. The best explanation for the difference in behaviour of the gases in the described situations is:

    (a) The molecules of air keep the two gases apart because air is a good heat insulator

    (b) The molecules of the two gases would be closer together when they are in an evacuated tube, than when there is air in the tube

    (c) When the gases enter the air filled tube they must diffuse through air molecules, whereas in an evacuated tube diffusion is faster because there are no air molecules through which the gas molecules must find their way

    (d) Chemical reactions between gases take place faster in an evacuated tube than in an air filled tube

    (e) In an evacuated tube the gas molecules can travel straight toward each other, whereas in an air filled tube expansion takes place

Go on to the next page

Diffusion Test (continued)

The following information is for items 14 and 15. A mixture containing equal numbers of molecules of each of two gases (X and Y) is placed in a large metal sphere which has a very tiny (microscopic) hole in it. The rate at which a gas will leak out of the sphere will depend on the number of times the molecules of that gas strike the side of the sphere. It is found that the mixture of gases leaking from the hole has many more molecules of gas X in it than molecules of gas Y.

14. From this observation one can conclude that:

    (a) The hole is not big enough for the heavy gas Y molecules to pass through

    (b) Gas X molecules have a faster average molecular speed than gas Y molecules

    (c) The molecules of gas X have a lower kinetic energy than gas Y molecules

    (d) The temperature of the two gases could not possibly have been the same

    (e) None of the above is a correct conclusion

15. A second conclusion one can draw from this observation is that:

    (a) The molecules of gas X have a higher average kinetic energy than gas Y molecules

    (b) The weight of each gas X molecule is greater than that of each gas Y molecule

    (c) The weight of each gas X molecule is less than that of each gas Y molecule

    (d) Gas X molecules have a slower average speed than gas Y molecules

    (e) Gas Y molecules would diffuse through another gas at a faster rate than gas X molecules

Go on to the next page

Diffusion Test (continued)

16. The over-all conclusion in this passage was:
    (a) Temperature is a measure of the average speed of molecules
    (b) If two gases are at equal temperatures, the lighter gas will diffuse faster through air than the heavier gas
    (c) The molecules of the lighter gas differ in a number of respects from the molecules of the heavier gas
    (d) If two gases are at the same temperature, they will have the same average kinetic energy
    (e) The gas with the fastest rate of diffusion has the weakest attractive forces among its molecules

STOP: Do not turn this page until you are asked to do so. If you are finished before time is called, check your work

PHASE CHANGE

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain phase change.

Phase change refers to the change that occurs when a solid melts, a liquid freezes or evaporates, or a gas condenses.

Consider the following reasoning concerning phase changes which take place in a tightly sealed jar which is three-quarters full of a liquid at room temperature and is heat insulated from the surroundings.

If the temperature of the liquid in the jar is increased, then the average speed of the molecules of the liquid increases. If the speed of the molecules of the liquid increases, then more molecules have enough speed to escape from the surface of the liquid or evaporate. If this happens, then there will be a greater number of molecules of vapour in the restricted space above the liquid.

Therefore, if the temperature of the liquid in the jar is increased, then there are a greater number of molecules of vapour in the restricted space above the liquid.

If there are a greater number of molecules above the liquid, then there is a greater chance that some of them will strike the liquid surface and be recaptured. If this happens, more molecules will condense from the vapour to the liquid phase.

Since more vapour molecules condense, then the rate of condensation of the vapour is greater than it was before the liquid was heated.

Therefore, if the temperature of the liquid in the jar is increased, then the rate of condensation of the vapour is greater than it was before the liquid was heated.

In other words, it may be concluded that if the temperature of a liquid is increased in an insulated, sealed, jar, then the rates of both evaporation and condensation increase.

Go on to the next page

PHASE CHANGE ANALOGY - A COMPARISON

One can explain evaporation and condensation of a liquid by comparing molecules to people at a school dance.

The jar may be thought of as the dance hall building. Think of the bystanders around the edge of the dance floor as being molecules in the liquid phase, and of the people actually dancing as molecules in the vapour phase. The dancers are dancing a rather slow number.

If the tempo of the music increases, more couples form and move out from the sidelines, just as when the temperature is raised, more molecules evaporate from the liquid.

If more couples "evaporate", there are a greater number of people dancing on the area of the floor restricted to dancers.

Therefore, as the tempo of the music increased, the number of people dancing increases.

As more couples dance, there will be a greater number of couples who get tired and return to the sidelines. In other words, they "condense" back to the liquid phase.

There are a greater number of couples leaving the floor per minute now than when the tempo of the music was slow. In other words, the rate of "condensation" has increased.

Therefore, if the tempo of the music is increased, the rates at which couples enter and leave the dance floor are greater than when the tempo of the music was slower. Just as the rates of evaporation and condensation increase with an increase in temperature so too the rates of couples forming and retiring increase with an increase in tempo of music.

Go on to the next page

PHASE CHANGE

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain phase change.

Phase change refers to the change that occurs when a solid melts, a liquid freezes or evaporates, or a gas condenses.

One can explain evaporation and condensation of a liquid by comparing molecules to people at a school dance.

Consider the following reasoning concerning phase changes which take place in a tightly sealed jar which is three-quarters full of a liquid at room temperature and is heat insulated from the surroundings.

The jar may be thought of as the dance hall building. Think of the bystanders around the edge of the dance floor as being molecules in the liquid phase, and of the people actually dancing as molecules in the vapour phase. The dancers are dancing a rather slow number.

If the temperature of the liquid in the jar is increased, then the average speed of the molecules of the liquid increases. If the speed of the molecules of the liquid increases, then more molecules have enough speed to escape from the surface of the liquid or evaporate. If this happens, then there will be a greater number of molecules of vapour in the restricted space above the liquid.

If the tempo of the music increases, more couples form and move out from the sidelines, just as when the temperature is raised, more molecules evaporate from the liquid.

If more couples "evaporate," there are a greater number of people dancing on the area of the floor restricted to dancers.

Therefore, if the temperature of the liquid in the jar is increased, then there are a greater number of molecules of vapour in the restricted space above the liquid.

Therefore, as the tempo of the music increases, the number of people dancing increases.

Go on to the next page

PHASE CHANGE

If there are a greater number of molecules above the liquid, then there is a greater chance that some of them will strike the liquid surface and be recaptured. If this happens, more molecules will condense from the vapour to the liquid phase.

As more couples dance, there will be a greater number of couples who get tired and return to the sidelines. In other words, they "condense" back to the liquid phase.

Since more vapour molecules condense, then the rate of condensation of the vapour is greater than it was before the liquid was heated.

There are a greater number of couples leaving the floor per minute now than when the tempo of the music was slow. In other words, the rate of "condensation" has increased.

Therefore, if the temperature of the liquid in the jar is increased, then the rate of condensation of the vapour is greater than it was before the liquid was heated.

Therefore, if the tempo of the music is increased, the rates at which couples enter and leave the dance floor are greater than when the tempo of the music was slower.

In other words, it may be concluded that if the temperature of a liquid is increased in an insulated, sealed, jar, then the rates of both evaporation and condensation increase.

Just as the rates of evaporation and condensation increase with an increase in temperature, so too the rates of couples forming and retiring increase with an increase in tempo of music.

Go on to the next page

PHASE CHANGE

Passage	Comparison (Analogy)
The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain phase change. Phase change refers to the change that occurs when a solid melts, a liquid freezes or evaporates, or a gas condenses. Consider the following reasoning concerning phase changes which take place in a tightly sealed jar which is three-quarters full of a liquid at room temperature and is heat insulated from the surroundings.	One can explain evaporation and condensation of a liquid by comparing molecules to people at a school dance. The jar may be thought of as the dance hall building. Think of the bystanders around the edge of the dance floor as being molecules in the liquid phase, and of the people actually dancing as molecules in the vapour phase. The dancers are dancing a rather slow number.
If the temperature of the liquid in the jar is increased, then the average speed of the molecules of the liquid increases. If the speed of the molecules of the liquid increases, then more molecules have enough speed to escape from the surface of the liquid or evaporate. If this happens, then there will be a greater number of molecules of vapour in the restricted space above the liquid.	If the tempo of the music increases, more couples form and move out from the sidelines, just as when the temperature is raised, more molecules evaporate from the liquid. If more couples "evaporate," there are a greater number of people dancing on the area of the floor restricted to dancers.
Therefore, if the temperature of the liquid in the jar is increased, then there are a greater number of molecules of vapour in the restricted space above the liquid.	

Go on to the next page

Phase Change (continued)

Passage	Comparison (Analogy)
If there are a greater number of molecules above the liquid, then there is a greater chance that some of them will strike the liquid surface and be recaptured. If this happens, more molecules will condense from the vapour to the liquid phase.	As more couples dance, there will be a greater number of couples who get tired and return to the side-lines. In other words, they "condense" back to the liquid phase.
Since more vapour molecules condense, then the rate of condensation of the vapour is greater than it was before the liquid was heated.	There are a greater number of couples leaving the floor per minute now than when the tempo of the music was slow. In other words, the rate of "condensation" has increased.
Therefore, if the temperature of the liquid in the jar is increased, then the rate of condensation of the vapour is greater than it was before the liquid was heated.	Therefore, if the tempo of the music is increased, the rates at which couples enter and leave the dance floor are greater than when the tempo of the music was slower. Just as the rates of evaporation and condensation increase with an increase in temperature, so too the rates of couples forming and retiring increase with an increase in tempo of music.
In other words, it may be concluded that if the temperature of a liquid is increased in an insulated, sealed, jar, then the rates of both evaporation and condensation increase.	

Go on to the next page

PHASE CHANGE ANALOGY TEST

1. Good is to bad as light is to:
   - (a) bulb
   - (b) dark
   - (c) evil
   - (d) angelic
   - (e) white

2. Jane is to John as girl is to:
   - (a) lady
   - (b) Miss
   - (c) boy
   - (d) woman
   - (e) Mister

3. Molecules are to temperature as people at a school dance are to:
   - (a) evaporation
   - (b) the dance floor
   - (c) the tempo of the music
   - (d) compression
   - (e) intermolecular forces

4. People dancing on the floor are to people standing along the sidelines as molecules in the gas phase are to:
   - (a) faster moving molecules
   - (b) the average kinetic energy of molecules
   - (c) the average speed of the molecules
   - (d) molecules in the liquid phase
   - (e) molecules evaporating

5. The jar is to the entire dance hall as the vapour in the jar is to the:
   - (a) people along the sidelines
   - (b) people dancing on the floor
   - (c) people in the band
   - (d) movement of people dancing
   - (e) rate of movement of people along the sidelines

Go on to the next page

Phase Change Analogy Test (continued)

6. People dancing are to couples forming and beginning to dance as molecules in the vapour are to:
   - (a) molecules in the liquid
   - (b) molecules evaporating from the liquid
   - (c) molecules condensing from the gas
   - (d) people along the sidelines
   - (e) faster moving molecules

7. The rate of movement of people dancing is to the tempo of the music as the average speed of the molecules is to the:
   - (a) pressure
   - (b) temperature
   - (c) volume
   - (d) number of molecules
   - (e) number of people

8. An increase in temperature of the liquid is to an increase in the number of molecules in the vapour as an increase in the tempo of the music is to:
   - (a) a greater number of people dancing
   - (b) a greater number of people along the sidelines
   - (c) a greater number of couples forming
   - (d) the average speed of the molecules
   - (e) all the couples in the dance hall

9. Couples forming and beginning to dance are to molecules evaporating as couples who stop dancing are to:
   - (a) molecules condensing
   - (b) molecules gasifying
   - (c) strong attractive forces among the molecules
   - (d) weak attractive forces among the molecules
   - (e) tired people

10. The number of people dancing is to the rate at which people leave the floor as the number of molecules in the vapour is to:
   - (a) the number of molecules in the liquid
   - (b) the temperature of the liquid

Go on to the next page

Phase Change Analogy Test (continuing)

(c) the rate at which molecules in the vapour condense

(d) the rate of movement of the dancers

(e) the rate of movement of the liquid molecules

Go on to the next page

PHASE CHANGE TEST

1. The initial conditions under which the reasoning in the passage began were:
   - (a) an open jar 3/4 full of liquid at room temperature and insulated from its surroundings
   - (b) a tightly sealed jar 3/4 full of liquid at room temperature insulated from its surroundings
   - (c) a jar full of vapour at room temperature insulated from its surroundings
   - (d) a jar 3/4 full of liquid and not at room temperature, but insulated from its surroundings
   - (e) a jar 3/4 full of liquid at room temperature and insulated from its surroundings

2. When the temperature of the liquid was raised:
   - (a) the average speed of the molecules remains the same because an average cannot change
   - (b) the average speed of the molecules decreased because there was more evaporation
   - (c) the average speed of the molecules increased because hotter molecules are lighter
   - (d) the average speed of the molecules increased because temperature gives an indication of the average speed of the molecules
   - (e) the average speed of the molecules decreased because the temperature is a measure of the average kinetic energy of the molecules

3. The reason why the number of molecules in the vapour increased when the temperature of the liquid increased was that:
   - (a) the rate of evaporation increased
   - (b) the Kinetic Molecular Theory of Matter explains the behaviour of the liquid
   - (c) there are attractive forces between molecules in the liquid
   - (d) there are larger average spaces between the molecules in the gas phase
   - (e) the temperature is an indication of the average speed of the molecules

Go on to the next page

Phase Change Test (continued)

4. Which of the following statements follows directly from the reasoning used in the passage?

    (a) The temperature of a liquid determines its boiling point

    (b) The average molecular speed of the molecules in the liquid determines the number of molecules in the vapour

    (c) If two samples of liquid contain the same amount of heat, then they will be at the same temperature

    (d) The vapour above the liquid will be at a higher temperature than the liquid in the jar

    (e) The same amount of heat is required to vaporize a certain number of molecules regardless of what liquid is used

5. The rate of evaporation of a liquid can be increased by:

    (a) decreasing the average kinetic energy of the molecules of the liquid

    (b) increasing the pressure on the liquid

    (c) increasing the number of molecules of liquid

    (d) decreasing the space above the liquid

    (e) increasing the temperature of the liquid

6. If the number of molecules decreased in the vapour space described in the passage, then:

    (a) the speed of the molecules in the liquid must have increased

    (b) the rate of evaporation must have increased

    (c) the temperature of the liquid in the jar must have decreased

    (d) the temperature of the molecules in the vapour must have increased

    (e) the size of the molecules in the vapour must have increased

Go on to the next page

7. A bottle of liquid is completely heat insulated from its surroundings and some of the liquid is allowed to evaporate. The evaporated molecules are removed immediately from the vicinity of the liquid. The temperature of the liquid in the bottle would:

   (a) increase

   (b) decrease

   (c) remain the same

   (d) not be predictable

   (e) increase and then decrease

8. Assume there are two identical SEALED bottles A and B containing the same amounts of the same liquid. There are twice as many molecules in the vapour above the liquid in bottle A as there are in bottle B. Which of the following statements best describes the above system?

   (a) The temperature of the liquid in bottle A is lower than the temperature of the liquid in bottle B

   (b) The average speed of the molecules in bottle A is less than the average speed of the molecules in bottle B

   (c) The two bottles could not contain the same liquid

   (d) The pressure in bottle A was less than the pressure in bottle B

   (e) The temperature of the liquid in bottle A is higher than the temperature of the liquid in bottle B

9. The average speed at which molecules move can be changed by:

   (a) changing the number of molecules

   (b) changing the potential energy of the molecules

   (c) changing the rate at which the molecules condense

   (d) changing the temperature of the molecules

   (e) changing the pressure on the molecules if the temperature is constant

Go on to the next page

10. The temperature of a substance is determined by the:
    (a) weight of a molecule of the substance
    (b) number of molecules or atoms
    (c) total weight of molecules or atoms
    (d) speed and number of molecules
    (e) average speed of its molecules

11. Which of the following decreases the evaporation rate of a liquid in an open container?
    (a) Raise the temperature of the liquid
    (b) Make the surface area of the liquid larger
    (c) Increase the average kinetic energy of the molecules
    (d) Decrease the average speed of the molecules
    (e) None of the above

12. If one wanted to get an indirect measure of the average speed of molecules of a substance one would use a/an:
    (a) ammeter
    (b) spectrometer
    (c) odometer
    (d) thermometer
    (e) barometer

13. Suppose there is a machine to separate molecules which have speeds greater than the average speed from those that move at a speed less than the average speed. The molecules with speeds less than the average speed would:
    (a) feel warmer than the molecules with speeds greater than the average speed
    (b) evaporate more slowly than the molecules with speeds greater than the average
    (c) have less heat, but more energy than the molecules with speeds greater than the average speed
    (d) have more heat but less energy than the molecules with speeds greater than the average speed
    (e) have more heat and more energy than the molecules with speeds greater than the average speed

Go on to the next page

14. Assume that you have a glass of water whose molecules have a certain average speed. A number of water molecules which had a greater average speed than the average speed of the water molecules in the glass were added to the water in the glass. Which of the following statements correctly describes the change which would occur?

    (a) The temperature of the water in the glass would decrease

    (b) The molecules added to the glass would speed up

    (c) The temperature of the molecules added to the water in the glass would increase

    (d) The temperature of the water in the glass would increase

    (e) The average kinetic energy of the molecules in the glass would decrease

15. Assume that you have two identical sealed jars A and B filled to the same level with the SAME liquid. It was determined that the average speed of the molecules in jar A was greater than the average speed of the molecules in jar B. Which of the following statements concerning these two jars is correct?

    (a) The number of molecules in the vapour above the liquid in jar A is less than the number in the vapour of jar B

    (b) The vapour above the liquid in jar B is hotter than the vapour in jar A

    (c) The molecules of liquid in jar A must be lighter than the molecules of liquid in jar B

    (d) The number of molecules in the vapour above the liquid in jar A is greater than the number in the vapour of jar B

    (e) None of these statements is correct

16. Which of the following choices best describes the rate of condensation of the vapour in the two sealed bottles in question 15? The rate of condensation of the vapour in:

    (a) bottle A is less than that in bottle B

    (b) bottle A is greater than that in bottle B

    (c) bottle A is the same as that in bottle B

Go on to the next page

(d) the two bottles cannot be predicted

(e) bottle A is greater than that in bottle B, but the temperature of the liquid in bottle A is lower

17. Consider the following statements which may or may not be true concerning the system described in the Phase Change passage.

I. The greater the rate of evaporation, the greater is the number of molecules in the vapour phase

II. The lower the temperature of the liquid, the greater is the rate of condensation of the vapour

Choose the correct description of the statements from the following:

(a) Statements I and II are in agreement and both are true

(b) Statements I and II are in agreement and both are false

(c) Statements I and II are not in agreement, I is false and II is true

(d) Statements I and II are not in agreement, I is true, II is false

(e) Statements I and II have no relationship to one another

18. After the temperature of the liquid in the sealed jar described in the passage was increased:

(a) the vapour molecules are farther apart

(b) the attractive forces among the vapour molecules decreased

(c) fewer molecules condensed because the temperature had been raised

(d) steam formed above the liquid

(e) the rate of condensation of vapour increased

19. The over-all conclusion of this passage was:

(a) Temperature is a measure of the average speed of molecules

(b) An increase in evaporation results in an increase in the amount of vapour above the liquid

Go on to the next page

(c) An increase in temperature of the liquid results in an increase in the rate of evaporation and condensation

(d) Evaporation of molecules is a cooling process

(e) Molecules which are closer together have stronger attractive forces

20. If the sealed jar described in the passage were at a certain temperature and suddenly one could somehow increase the surface area without changing the temperature of the liquid, then:

(a) the rate of evaporation would momentarily decrease

(b) the rate of condensation would momentarily increase

(c) the volume occupied by the liquid would decrease considerably

(d) the average speed of the molecules in the liquid would decrease

(e) a vacuum would result in the space above the liquid

STOP: Do not turn this page until you are asked to do so. If you are finished before time is called, check your work.

COMPRESSION

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas compression.

Gas compression refers to decreasing the volume by increasing the pressure on a fixed amount of gas in a container.

Consider the following reasoning concerning the compression of a gas by a piston at a constant temperature which is below a particular temperature specific to each gas.

If the gas is compressed continuously at constant temperature, then the molecules of the gas move closer and closer together. If the molecules move closer and closer together, then the attractive forces among the molecules get stronger and stronger. If this happens, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

Therefore, if the gas is compressed continuously at constant temperature, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

If the attractive forces are strong enough to cause cluster formation, these clusters increase in size until they contain many molecules and become very large and heavy. If this happens, eventually the largest clusters of molecules can no longer be held in suspension by the gaseous molecules.

Since the largest clusters can no longer be held in suspension, then the largest clusters of molecules will precipitate as droplets of liquid.

Therefore, if a gas is compressed continuously at constant temperature, then the largest clusters of molecules will precipitate as droplets of liquid.

In other words, it may be concluded that if a gas is compressed continuously at a constant temperature which is below a particular temperature specific to each gas, the gas will liquify.

Go on to the next page

COMPRESSION ANALOGY - A COMPARISON

The compression of a gas can be explained by comparing molecules of the gas to people.

Consider what happens to people when they are "pushed" closer together as they are in moving from the country into the city.

If people are "pushed" closer and closer together as they are when they live closer and closer together, then attractive forces among the people increase, just as they do among molecules when they are pushed closer together.

As people get to know each other well, the attractive forces increase and small informal groups of people such as friendship groups or "gangs" are formed. These informal groups compare to the small clusters of molecules.

Therefore, as people are brought closer together, small informal groups begin to form.

Small informal groups may grow in size until they become very large containing a number of informal groups. These larger groups are called formal groups. Examples are Girl Guides, Boy Scouts, Sports Leagues, and Motorcycle Clubs.

These large formal groups become very noticeable within the society at large. They cannot be ignored or "held in suspension" by society, just as the largest clusters of molecules can no longer be held in suspension by the gaseous molecules.

The members of these formal groups have "precipitated" from society to do their own thing.

Therefore, if people are pushed together closer and closer, they will form large formal groups just as molecules of a compressed gas form droplets of liquid.

Go on to the next page

COMPRESSION

The following paragraphs illustrate how the Kinetic Molecular theory can be used to explain gas compression.

Gas compression refers to decreasing the volume by increasing the pressure on a fixed amount of gas in a container.

The compression of a gas can be explained by comparing molecules of the gas to people.

Consider the following reasoning concerning the compression of a gas in a piston at a constant temperature which is below a particular temperature specific to each gas.

Consider what happens to people when they are "pushed" closer and closer together as they are in moving from the country into the city.

If the gas is compressed continuously at constant temperature, then the molecules of the gas move closer and closer together. If the molecules move closer and closer together, then the attractive forces among the molecules get stronger and stronger.

If people are "pushed" closer and closer together as they are when they live closer and closer together, then attractive forces among the people increase, just as they do among molecules when they are pushed closer together.

If this happens, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

As people get to know each other well, the attractive forces increase and small informal groups of people such as friendship groups or "gangs" are formed. These informal groups compare to the small clusters of molecules.

Therefore, if the gas is compressed continuously at constant temperature, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.

Therefore, as people are brought closer together, small informal groups begin to form.

Go on to the next page

Compression (continued)

If the attractive forces are strong enough to cause cluster formation, these clusters increase in size until they contain many molecules and become very large and heavy. If this happens, eventually the largest clusters of molecules can no longer be held in suspension by the gaseous molecules.

Small informal groups may grow in size until they become very large containing a number of informal groups. These larger groups are called formal groups. Examples are Girl Guides, Boy Scouts, Sports Leagues, and Motorcycle Clubs.

Since the largest clusters can no longer be held in suspension, then the largest clusters of molecules will precipitate as droplets of liquid.

These large formal groups become very noticeable within the society at large. They cannot be ignored or "held in suspension" by society, just as the largest clusters of molecules can no longer be held in suspension by the gaseous molecules.

The members of these formal groups have "precipitated" from society to do their own thing.

Therefore, if a gas is compressed continuously at constant temperature, then the largest clusters of molecules will precipitate as droplets of liquid.

In other words, it may be concluded that if a gas is compressed continuously at a constant temperature which is below a particular temperature specific to each gas, the gas will liquify.

Therefore, if people are pushed together closer and closer, they will form large formal groups just as molecules of a compressed gas form droplets of liquid.

Go on to the next page

COMPRESSION

Passage	Comparison (Analogy)
The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas compression. Gas compression refers to decreasing the volume by increasing the pressure on a fixed amount of gas in a container. Consider the following reasoning concerning the compression of a gas in a piston at a constant temperature which is below a particular temperature specific to each gas.	The compression of a gas can be explained by comparing molecules of the gas to people. Consider what happens to people when they are "pushed" closer together as they are in moving from the country into the city.
If the gas is compressed continuously at constant temperature, then the molecules of the gas move closer and closer together. If the molecules move closer and closer together, then the attractive forces among the molecules get stronger and stronger.	If people are "pushed" closer and closer together as they are when they live closer and closer together, then attractive forces among the people increase, just as they do among molecules when they are pushed closer together.
If this happens, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.	As people get to know each other well, the attractive forces increase and small informal groups of people such as friendship groups or "gangs" are formed. These informal groups compare to the small clusters of molecules.

Go on to the next page

Compression (continued)

Passage	Comparison (Analogy)
Therefore, if the gas is compressed continuously at constant temperature, the attractive forces among the molecules eventually become strong enough to hold the molecules together in clusters.	Therefore, as people are brought closer together, small informal groups begin to form.
If the attractive forces are strong enough to cause cluster formation, these clusters increase in size until they contain many molecules and become very large and heavy. If this happens, eventually the largest clusters of molecules can no longer be held in suspension by the gaseous molecules.	Small informal groups may grow in size until they become very large containing a number of informal groups. These larger groups are called formal groups. Examples are Girl Guides, Boy Scouts, Sports Leagues, and Motorcycle Clubs.
Since the largest clusters can no longer be held in suspension, then the largest clusters of molecules will precipitate as droplets of liquid.	These large formal groups become very noticeable within the society at large. They cannot be ignored or "held in suspension" by society, just as the largest clusters of molecules can no longer be held in suspension by the gaseous molecules. The members of these formal groups have "precipitated" from society to do their own thing.
Therefore, if a gas is compressed continuously at constant temperature, then the largest clusters of molecules will precipitate as droplets of liquid.	Therefore, if people are pushed together closer and closer, they will form large formal groups just as molecules of a compressed gas form droplets of liquid.

Go on to the next page

Compression (continued)

Passage	Comparison (Analogy)
In other words, it may be concluded that if a gas is compressed continuously at a constant temperature which is below a particular temperature specific to each gas, the gas will liquify.	

Go on to the next page

COMPRESSION ANALOGIES TEST

1. Good is to bad as light is to:
    (a) bulb
    (b) dark
    (c) evil
    (d) angelic
    (e) white

2. Jane is to John as girl is to:
    (a) lady
    (b) Miss
    (c) boy
    (d) woman
    (e) Mister

3. People are to attractive forces among people as molecules are to:
    (a) repulsive forces among molecules
    (b) the temperature of the gas
    (c) repulsive forces among people
    (d) attractive forces among molecules
    (e) the pressure of the gas

4. Molecules in a gas at room pressure are to molecules in a compressed gas as people who live far apart are to:
    (a) molecules
    (b) people who move very quickly
    (c) weak attractive forces
    (d) strong attractive forces
    (e) people who live close together

5. Groups of people are to groups of molecules as friendship is to:
    (a) love
    (b) hatred
    (c) attractive forces
    (d) repulsive forces
    (e) cities

Go on to the next page

Compression Analogies Test (continued)

6. Compression of a gas is to molecular clusters as people living in cities are to:
   (a) people living in the country
   (b) people moving more slowly
   (c) attractive forces
   (d) gangs
   (e) love

7. People who live close together are to friendship as molecules which are far apart are to:
   (a) heating of a gas
   (b) weak attractive forces
   (c) compression of a gas
   (d) strong attractive forces
   (e) love

8. Compression of a gas is to expansion of a gas as people moving from the country to the city are to:
   (a) strong attractive forces
   (b) weaker attractive forces
   (c) people moving from the city to the country
   (d) molecules moving closer together
   (e) molecules moving farther apart

9. People are to large formal groups as molecules are to:
   (a) motorcycle gangs
   (b) strong attractive forces
   (c) weak attractive forces
   (d) noticeable groups of people
   (e) droplets of liquid

10. Continuous compression of a gas is to droplets of liquid as moving from the country to the city is to:
   (a) friendship groups
   (b) large formal groups
   (c) greater hostility among groups
   (d) social chaos
   (e) molecules of a gas

Go on to the next page

COMPRESSION TEST

1. The stated conditions under which the reasoning in the passage holds were:

   (a) The gas is compressed continuously at constant pressure which is below a particular temperature specific to each gas

   (b) The gas is compressed continuously at a constant temperature which is below a particular temperature specific to the gas

   (c) Gases which have intermolecular forces are compressed

   (d) The compressed gas is assumed to have no intermolecular forces, but must be below a specific temperature during compression

   (e) The gas is compressed continuously at a particular temperature specific to the gas

2. When the molecules are close to each other:

   (a) the repulsive forces become weaker

   (b) the effect of the attractive forces among molecules becomes less noticeable

   (c) the molecules become smaller

   (d) the attractive forces among the molecules are dependent on the temperature

   (e) the attractive forces become stronger

3. The reason why the molecules began to group together to form clusters is that:

   (a) the temperature was held constant during the compression

   (b) the attractive forces concentrated more and more in the molecules as they became smaller and smaller

   (c) the average speed of the molecules decreased

   (d) the attractive forces among the molecules became stronger when the molecules were pushed closer together

   (e) the molecules began to form clusters because they were cooler

Go on to the next page

Compression Test (continued)

4. Which one of the following statements follows directly from the reasoning used in the passage?

   (a) If a gas has no intermolecular forces, it would not condense when compressed

   (b) A gas condenses when compressed because compression cools the gas

   (c) A liquid occupies less volume than a gas because the molecules of a liquid are smaller than those of the gas due to compression

   (d) The molecules in a compressed gas move faster even though the gas is held at constant temperature

   (e) A gas which has intermolecular forces will ultimately condense when compressed no matter what the temperature of the gas is as long as the temperature is held constant

5. When the volume of a certain amount of gas is decreased, the:

   (a) temperature decreases

   (b) molecules decrease in size

   (c) molecules decrease in size; therefore, the attractive forces among molecules increase

   (d) weight of the molecules decreases

   (e) attractive forces among the molecules increase

6. When gases are compressed at constant temperature, the molecules begin to form clusters when the:

   (a) molecules slow down enough

   (b) average kinetic energy decreases enough

   (c) molecules are close enough

   (d) molecules become small enough

   (e) volume is increased enough

7. While a gas is being compressed the:

   (a) molecules become smaller

   (b) attractive forces increase

   (c) temperature of the gas decreases

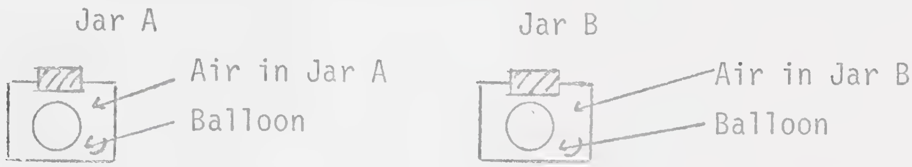
   (d) kinetic energy of the molecules decreases

   (e) molecular speed decreases

Go on to the next page

Compression Test (continued)

Use the information below to answer questions 8 to 10 inclusive.



The two balloons were blown up with air so that they had identical volumes when they were at room pressure. They were then inserted into the jars which were stoppered. The pressures of the air inside the jars were changed so that the balloon in jar A became much larger than the balloon in jar B as shown in the diagram. The temperature of the jars and contents were the same in both cases.

8. One can conclude that the air pressure:
   - (a) is greater in jar A than in jar B
   - (b) is greater in the balloon in jar A than it is in the balloon in jar B
   - (c) is less in jar A than in jar B
   - (d) is the same in the balloon in jar A as it is in the balloon in jar B
   - (e) is greater in jar A than in the balloon in jar A

9. One can conclude that the strength of the attractive forces among the molecules after the pressure was changed:
   - (a) is greater in the balloon in jar A than in the balloon in jar B
   - (b) is the same in the balloon in jar A as in the balloon in jar B
   - (c) is greater in jar A than in jar B
   - (d) is less in jar A than in jar B
   - (e) is greater in jar B than in the balloon in jar B

10. Which molecules would be the nearest to forming clusters of molecules?
    - (a) The gas molecules inside jar A
    - (b) The gas molecules inside the balloon of jar A
    - (c) The gas molecules inside the balloon of jar B

Go on to the next page

(d) The gas molecules inside jar B

(e) None of the above

11. If a gas were allowed to expand at constant temperature:

    (a) the molecules would become larger

    (b) the intermolecular forces of the gas would increase

    (c) the molecules would move farther apart

    (d) the kinetic energy of the molecules would increase

    (e) the distance between the molecules would decrease

12. Equal volumes of gaseous water and gaseous ammonia were placed into two cylinders at the same temperature. The two gases were both compressed to equal volumes and the water molecules began to form clusters whereas the ammonia did not. The temperature was kept the same in both cylinders throughout the compression. One may conclude from these observations that:

    (a) gaseous water is easier to compress than gaseous ammonia

    (b) the attractive forces among the water molecules are stronger than those among the ammonia molecules

    (c) the water molecules had greater kinetic energy than the ammonia molecules

    (d) the attractive forces among the water molecules are weak in comparison to those among the ammonia molecules

    (e) the water molecules have a greater average speed than the ammonia molecules

13. If you had a sample of liquid water molecules and a sample of gaseous water molecules, you could conclude:

    (a) the gaseous water molecules were at a higher temperature than the liquid water molecules

    (b) the gaseous water molecules are at the same temperature as the liquid water molecules

    (c) the attractive forces among the molecules in the liquid are stronger than those among the molecules in the gas

    (d) the molecules in the gas are larger than those in the liquid

    (e) the two samples must be under different pressures

Go on to the next page

14. Since each known substance on the earth can exist as a gas, a liquid, and a solid, we may conclude:

    (a) no substance can get any colder than its freezing temperature

    (b) the Kinetic Molecular Theory is a perfect theory

    (c) all gases can be turned to liquids simply by compressing them

    (d) there can only be three states of matter

    (e) all molecules must have attractive forces for each other

15. Consider two cylinders containing equal numbers of molecules of gases X and Y. Both gases are at the same temperature. The molecules of gas X are a greater average distance apart than the molecules of gas Y. Which of the following statements is a conclusion which follows from this information?

    (a) The molecules in gas Y have weaker attractive forces among them than the molecules of gas X

    (b) The average kinetic energy of gas X molecules is greater than that of gas Y molecules

    (c) The volume of the cylinder containing gas X is smaller the volume of the cylinder containing gas Y

    (d) The pressure of the cylinder containing gas Y is greater than the pressure on the cylinder containing gas X

    (e) The average kinetic energy of gas X molecules is less than that of gas Y molecules

16. Assume that attractive force is the only factor which determines how much a gas must be compressed before it forms a liquid. When gases A and B were compressed under equal pressures and temperatures to form liquids, gas A began to liquify before gas B. After both gases have formed liquids, the two liquids were allowed to evaporate at the same temperature. Which of the following statements would be true?

    (a) Liquid A would evaporate faster than liquid B

    (b) Liquid A would evaporate slower than liquid B

    (c) You cannot predict the rate of evaporation from the information given

Go on to the next page

(d) Liquid A would evaporate at the same rate as liquid B because they both came from compressed gases

(e) Gas B has stronger attractive forces among its molecules than does gas A

17. In question 16, the gas molecules began to precipitate as droplets of liquid when:

(a) the gas was cooled

(b) the weight of the molecules increased enough

(c) the distance between the gas molecules increased

(d) the gas molecules could no longer hold them in suspension

(e) the volume of the gas was ultimately increased

18. Clouds are composed of large enough clusters of water to be visible to the naked eye. Yet, not every cloud produces a rain storm. This is because the:

(a) clusters of water in the cloud are held up by the repulsive forces between the water molecules and the air molecules

(b) clusters of water in the cloud are held in the cloud by the attractive forces of the other clusters in the cloud

(c) clusters of water in the cloud are still small enough so they are held in suspension by air molecules

(d) attractive forces among water molecules are very weak

(e) attractive forces among water molecules are very strong

19. The over-all conclusion in the passage was:

(a) When a gas is compressed, the temperature of the gas remains constant

(b) By compressing the gas continuously, the molecules of the gas become smaller and therefore have stronger attractive forces because they become concentrated

Go on to the next page

Compression Test (continued)

(c) Compressing a gas decreased the attractive forces among molecules, therefore, the gas condenses

(d) If a gas is compressed continuously at a constant temperature which is below a particular temperature specific to the gas will condense to form a liquid

(e) The closer molecules are to each other, the stronger the attractive forces among them

20. If the pressure above a liquid is reduced the:

(a) average speed of the molecules in the liquid increases

(b) average kinetic energy of the molecules in the liquid increases

(c) concentration of molecules above the liquid increases

(d) rate of evaporation of the liquid will increase

(e) temperature of the molecules above the liquid will increase

STOP: Do not turn this page until you are asked to do so. If you are finished before time is called, check your work.

DIFFUSION

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas diffusion.

Gas diffusion refers to the spontaneous mixing of two or more gases when they are placed in contact with each other.

Consider the following reasoning concerning the diffusion through air contained in a pipe of a mixture of equal amounts of two pure gases whose molecules have very different weights.

If the temperature of the two gases in the mixture is the same, then the molecules of the gases have the same kinetic energy. If the molecules have the same kinetic energy, then the lighter molecules have greater average speed than the heavier molecules. If this happens, the lighter gas molecules travel their zig-zag course or diffuse faster among the air molecules in the pipe than the heaview gas molecules.

Therefore, if the temperatures of the two gases in the mixture are equal, the lighter gas traverses or diffuses faster among the air molecules in the pipe than the heavier gas.

If the lighter gas diffuses faster, then the average-speed light molecules reach the end of the pipe before the average-speed heavy molecules. If this happens, a sample removed at the end of the pipe at this time will be richer in light molecules than in heavy molecules.

Since the sample is richer in light molecules, then by repeatedly diffusing, collecting, and re-diffusing the sample, the light molecules can be separated from nearly all of the heavy molecules.

Therefore, if the temperatures of the two gases in the mixture are equal, then by repeatedly diffusing, collecting, and re-diffusing the sample, the light molecules can be separated from nearly all of the heavy molecules.

In other words, it may be concluded that a mixture of the two gases, whose molecules have very different weights, can be separated by diffusion.

Go on to the next page

DIFFUSION ANALOGY - A COMPARISON

Gas diffusion can be explained by comparing molecules of a gas to a group of students mixing with the crowd after entering a busy fairground.

Assume that half the students weigh 100 pounds and that the other half weigh 250 pounds. Furthermore, assume that all students have equal strength, just as both gases in the mixture have the same temperature.

If all students have the same strength, they will all have the same average kinetic energy because while the 100 pound students are lighter, their average speed will be greater as they move among the people at the fair. If their average speed is greater, the leading light students will travel farther in the same amount of time along the fairground than the leading heavier students. This is comparable to light gas molecules diffusing faster than the heavy gas molecules.

The average-speed light students will reach the opposite end of the fairground faster than the average-speed heavy students. If the students who are first to arrive at the far end of the fairground are gathered into a group, then this group will be considerably richer in light students than in heavy students.

This group of students is then allowed to enter a second fairground. Those who arrive first at the far end of the second fairground are gathered and started into a third fairground. This process is repeated through a number of fairgrounds. The resulting collection of students at the far end of the last fairground will contain mostly light students and very few heavy ones.

Therefore, the light and heavy students have been separated, just as the light and heavy gases were separated.

Go on to the next page

DIFFUSION

The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas diffusion.

Gas diffusion refers to the spontaneous mixing of two or more gases when they are placed in contact with each other.

Gas diffusion can be explained by comparing molecules of a gas to a group of students mixing with the crowd after entering a busy fair-ground.

Consider the following reasoning concerning the diffusion through air contained in a pipe of a mixture of equal amounts of two pure gases whose molecules have very different weights.

Assume that half the students weigh 100 pounds and that the other half weigh 250 pounds. Furthermore, assume that all students have equal strength, just as both gases in the mixture have the same temperature.

If the temperature of the two gases in the mixture is the same, then the molecules of the gases have the same kinetic energy. If the molecules have the same kinetic energy then the lighter molecules have greater average speed than the heavier molecules. If this happens, the lighter gas molecules travel their zig-zag course or diffuse faster among the air molecules in the pipe than the heavier gas molecules.

If all students have the same strength, they will all have the same kinetic energy because while the 100 pound students are lighter, their average speed will be greater as they move among the people at the fair. If their average speed is greater, the leading light students will travel farther in the same amount of time along the fairground than the leading heavier students.

Therefore, if the temperatures of the two gases in the mixture are equal, the lighter gas traverses or diffuses faster among the air molecules in the pipe than the heavier gas.

This is comparable to light gas molecules diffusing faster than the heavy molecules.

Go on to the next page

Diffusion (continued)

If the lighter gas diffuses faster, then the average-speed light molecules reach the end of the pipe before the average-speed heavy molecules. If this happens, a sample removed at the end of the pipe and at this time will be richer in light molecules than in heavy molecules.

The average-speed light students will reach the opposite end of the fairground faster than the average-speed heavy students. If the students who are first to arrive at the far end of the fairground are gathered into a group, then this group will be considerably richer in light students than in heavy students.

Since the sample is richer in light molecules, then by repeatedly diffusing, collecting, and re-diffusing the sample, the light molecules can be separated from nearly all of the heavy molecules.

This group of students is then allowed to enter a second fairground. Those who arrive first at the far end of the second fairground are gathered and started into a third fairground. This process is repeated through a number of fairgrounds. The resulting collection of students at the far end of the last fairground will contain mostly light students and very few heavy ones.

Therefore, if the temperatures of the two gases in the mixture are equal, then by repeatedly diffusing, collecting, and re-diffusing the sample, the light molecules can be separated from nearly all of the heavy molecules.

In other words, it may be concluded that a mixture of the two gases, whose molecules have very different weights, can be separated by diffusion.

Therefore, the light and heavy students have been separated, just as the light and heavy gases were separated.

Go on to the next page

DIFFUSION

Passage	Comparison (Analogy)
The following paragraphs illustrate how the Kinetic Molecular Theory can be used to explain gas diffusion. Gas diffusion refers to the spontaneous mixing of two or more gases when they are placed in contact with each other. Consider the following reasoning concerning the diffusion through air contained in a pipe of a mixture of equal amounts of two pure gases whose molecules have very different weights.	Gas diffusion can be explained by comparing molecules of a gas to a group of students mixing with the crowd after entering a busy fairground. Assume that half the students weigh 100 pounds and that the other half weigh 250 pounds. Furthermore, assume that all students have equal strength, just as both gases in the mixture have the same temperature.
If the temperature of the two gases in the mixture is the same, then the molecules of the gases have the same kinetic energy. If the molecules have the same kinetic energy, then the lighter molecules have greater average speed than the heavier molecules. If this happens, the lighter gas molecules travel their zig-zag course or diffuse faster among the air molecules in the pipe than the heavier gas molecules.	If all students have the same strength, they will all have the same kinetic energy because while the 100 pound students are lighter, their average speed will be greater as they move among the people at the fair, If their average speed is greater, the leading light students will travel farther in the same amount of time along the fairground than the leading heavier students. This is comparable to light gas molecules diffusing faster than the heavy gas molecules.

Go on to the next page

Diffusion (continued)

Passage	Comparison (Analogy)
Therefore, if the temperatures of the two gases in the mixture are equal, the lighter gas traverses or diffuses faster among the air molecules in the pipe than the heavier gas.	
If the lighter gas diffuses faster, then the average-speed light molecules reach the end of the pipe before the average-speed heavy molecules. If this happens, a sample removed at the end of the pipe and at this time will be richer in light molecules than in heavy molecules.	The average-speed light students will reach the opposite end of the fairground faster than the average-speed heavy students. If the students who are first to arrive at the far end of the fairground are gathered into a group, then this group will be considerably richer in light students than in heavy students.
	This group of students is then allowed to enter a second fairground. Those who arrive first at the far end of the second fairground are gathered and started into a third fairground. This process is repeated through a number of fairgrounds. The resulting collection of students at the far end of the last fairground will contain mostly light students and very few heavy ones.

Go on to the next page

Diffusion (continued)

Passage	Comparison (Analogy)
Therefore, if the temperatures of the two gases in the mixture are equal, then by repeatedly diffusing, collecting, and re-diffusing the sample, the light molecules can be separated from nearly all of the heavy molecules. In other words, it may be concluded that a mixture of the two gases, whose molecules have very different weights, can be separated by diffusion.	Therefore, the light and heavy students have been separated, just as the light and heavy gases were separated.

Go on to the next page

DIFFUSION ANALOGY TEST

1. Good is to bad as light is to:
   (a) bulb
   (b) dark
   (c) evil
   (d) angelic
   (e) white

2. Jane is to John as girl is to:
   (a) lady
   (b) Miss
   (c) boy
   (d) woman
   (e) Mister

3. The original group of students is to their movement among the people at the fair as the gas molecules in the mixture are to:
   (a) temperature
   (b) pressure
   (c) air molecules
   (d) diffusion through air
   (e) speed of the molecules of the mixture

4. The 100 pound and 250 pound students are to their equal strength as the molecules of the two gases in the mixture are to:
   (a) their equal average volumes
   (b) their equal average speeds
   (c) their equal temperature
   (d) their equal average numbers of molecules
   (e) their equal average potential energies

5. The average speed of the 100 pound students is to the average molecular speed of the lighter gas molecules as the average speed of the 250 pound students is to:
   (a) the average kinetic energy of the heavier gas molecules
   (b) the average temperature of the heavier gas molecules
   (c) the average temperature of the lighter gas molecules

Go on to the next page

(d) the average pressure of the heavier gas molecules

(e) the average molecular speed of the heavier gas molecules

6. The molecules in the mixture of gases are to the air molecules as the students are to:

   (a) the speed of the students

   (b) the people at the fair

   (c) the strength and stamina of the students

   (d) the temperature of the air

   (e) the length of the students' legs

7. The students are to the fairground as the molecules of the mixture are to:

   (a) the heavy molecules

   (b) the light molecules

   (c) the pipe

   (d) air molecules

   (e) the obstacles

8. The equal kinetic energy of the students is to their equal strength as the equal kinetic energy of the molecules is to:

   (a) their equal molecular size

   (b) their equal temperature

   (c) their equal volumes

   (d) their equal numbers of molecules

   (e) their equal pressures

9. The sample taken which contains more light than heavy molecules is to the end of the pipe as the group of students which contains more 100 pound students than 250 pound students is to:

   (a) sample selection

   (b) the people at the fair

   (c) the fairground

   (d) the opposite end of the fairground

   (e) the students at the fair

Go on to the next page

Diffusion Analogy Test (continued)

10. The number of light students in the group collected at the opposite end of the fairground is to the few heavy students as the number of light molecules in the sample taken at the end of the pipe is to:

(a) the original gas mixture

(b) a few heavy molecules

(c) more light molecules

(d) a few light molecules

(e) a pure sample of heavy molecules

DIFFUSION TEST

1. The stated conditions under which the reasoning in the passage holds were:
   - (a) The mixture of the two pure gases whose molecules have different molecular weights was allowed to diffuse through a vacuum
   - (b) The two pure gases were not at the same temperature originally
   - (c) The mixture of two gases whose molecules have different molecular weights was allowed to diffuse through air
   - (d) The mixture of two pure gases was separated into the separate gases before they were allowed to diffuse through air
   - (e) The mixture of two pure gases whose molecules had the same weights was allowed to diffuse through air

2. Which of the following statements about the two gases in the passage is correct?
   - (a) The molecules of the lighter gas move faster because the lighter molecules have more kinetic energy than the heavier molecules
   - (b) The molecules of the lighter gas move faster because they are at a higher temperature than the molecules of the heavier gas
   - (c) The molecules of the lighter gas move faster than the molecules of the heavier since the light and heavy molecules have the same average kinetic energy
   - (d) If the temperature of both gases was increased, the molecules of the heavier gas will then move as fast as the molecules of the lighter gas
   - (e) The two gases would move at the same speed if they were at the same temperature

3. The lighter gas diffuses faster than the heavier gas because:
   - (a) The lighter gas molecules have a greater average speed than the heavier gas molecules
   - (b) The Kinetic Molecular Theory of Matter indicates that the difference in rates of diffusion of gases is caused by a difference in molecular volume
   - (c) The attractive forces among the molecules of the heavier gas are greater than the attractive forces among the molecules of the lighter gas

Go on to the next page

(d) The heavier gas molecules, being bigger, have more momentum

(e) The attractive forces among the molecules of the heavier gas are less than the attractive forces among the molecules of the lighter gas

4. Which one of the following statements follows directly from the reasoning used in the passage?

(a) Two gases which have molecules which weigh the same would have the same temperature

(b) The kinetic energy of the light gas molecules is different from the kinetic energy of the heavy gas molecules

(c) The gas having the slowest rate of diffusion will arrive at a certain point after the gas having a faster rate of diffusion

(d) Molecules move faster when they diffuse through air than do the air molecules

(e) When considering diffusion of a gas through air, the air molecules are assumed to be motionless

5. Since the two gases had the same temperature, they had the same:

(a) molecular volume

(b) average kinetic energy

(c) amount of heat

(d) average speed of molecules

(e) average distance between the molecules

Go on to the next page

Diffusion Test (continued)

Questions 6 and 7 refer to the following situation. A student uncorks two identical bottles in a still room (no air currents). Each bottle contains a different gas, but both gases are at the same temperature. He places the uncorked bottles beside each other and sits down about six feet away from them. He smells the odour of gas A before the odour of gas B.

6. Which of the following statements concerning the gases is correct?
   (a) Gas A travels through air by the process of diffusion slower than gas B
   (b) Gas A diffuses at a faster rate than gas B
   (c) Gas B has a greater average molecular speed than gas A
   (d) The average kinetic energy of gas A molecules is greater than the average kinetic energy of gas B molecules
   (e) Since the molecules of gas A are lighter than the molecules of gas B, gas B molecules will diffuse faster

7. Which statement about the molecules of the gases is correct?
   (a) The average kinetic energy of the molecules of gas A is greater than the average kinetic energy of the molecules of gas B
   (b) The average speed of the molecules of both gases is the same
   (c) The average speed of the gas molecules will be greater than the average speed of the air molecules
   (d) The average speed of the molecules of gas A is greater than the average speed of the molecules of gas B
   (e) The average speed of the gas molecules will be less than the average speed of the air molecules

Go on to the next page

Diffusion Test (continued)

Questions 8 to 13 inclusive refer to the following diagram:

Initially the hypodermic syringe on the left contains gas A and the syringe on the right contains gas B. Both gases are at the same temperature. The glass tube is filled with air in which there are no air currents. It is known that when gas A and B meet they react chemically to form a white smoke. Gases A and B are different gases in each of the following experiments.

8. In the first experiment, a small amount of each of the gases is injected into the tube at the same time. After a period of time a smoke is observed in region 1. This indicates:

   (a) The molecular weight of gas A is less than the molecular weight of gas B

   (b) The average kinetic energy of gas A molecules is greater than the average kinetic energy of gas B molecules

   (c) The molecular weight of gas A is greater than the molecular weight of air

   (d) The weight of the molecules of gas A is greater than the weight of the molecules of gas B

   (e) The average kinetic energy of gas A molecules is less than the average kinetic energy of gas B molecules

9. In the second experiment, the smoke is first observed in region 2 after a small amount of each of the gases (not the same two as in question 8) was injected into the tube at the same time. From this observation one could conclude:

   (a) The rates of diffusion of the two gases must be equal

   (b) The potential energies of the two gases must be equal

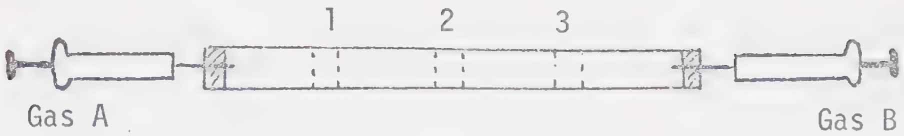
   (c) If it were not known that the temperatures of the two gases A and B were equal, this would indicate that the temperatures were equal

   (d) The molecular weight of gas A is greater than the molecular weight of gas B

   (e) The gases in hypodermic syringes A and B would have to be the same gas

Go on to the next page

Diffusion Test (continued)



10. In a third experiment it was noted that when gases A and B were at the same temperature, initially the smoke formed in region 3. If gas B was heated to a temperature above the temperature of gas A, in what region would you observe the formation of smoke?

    (a) To the right of region 3

    (b) To the left of region 3

    (c) In region 3

    (d) In region 1

    (e) In region 2

11. In a fourth experiment, two gases A and B were injected. A white smoke was first observed in region 3. Then the two were replaced by two chemicals X and Y which had identical molecular weights to gases A and B, respectively. The air in the glass tube was replaced with water. The experiment was then repeated by injecting the chemicals X and Y into the water. When the two chemicals met, a white solid was formed. The results of the two experiments were compared. Using your knowledge about the diffusion process, which of the following predictions is a correct one?

    (a) You cannot make any predictions because the experiments are not comparable

    (b) The white solid would form to the right of region 3

    (c) The white solid would form to the left of region 3

    (d) The white solid would form in region 3, but it would take much longer to form than in the case of the white smoke formation

    (e) The white solid would form in region 3, but it would not take nearly as long as it did for the white smoke to form

12. In a fifth experiment, with the glass tube again filled with air, the two gases A and B were injected at the same time and allowed to stand for some considerable period of time after the smoke was first observed in region 3. Smoke was then observed over the entire length of the tube. This is an example of:

    (a) air currents

    (b) convection

    (c) expansion

    (d) diffusion

    (e) condensation

Go on to the next page

Diffusion Test (continued)

13. In a sixth experiment gases A and B were injected into the tube filled with air. It was noted that it took ten minutes for the smoke to appear in region 3. Then all of the air was removed from the tube and the two gases were injected. The entire tube filled with white smoke immediately. The best explanation for the difference in behaviour of the gases in the described situations is:

    (a) The molecules of air keep the two gases apart because air is a good heat insulator

    (b) The molecules of the two gases would be closer together when they are in an evacuated tube, then when there is air in the tube

    (c) When the gases enter the air filled tube they must diffuse through air molecules, whereas in an evacuated tube diffusion is faster because there are no air molecules through which the gas molecules must find their way

    (d) Chemical reactions between gases take place faster in an evacuated tube than in an air filled tube

    (e) In an evacuated tube the gas molecules can travel straight toward each other, whereas, in an air filled tube expansion takes place.

The following information is for items 14 and 15. A mixture containing equal numbers of molecules of each of two gases (X and Y) is placed in a large metal sphere which has a very tiny (microscopic) hole in it. The rate at which a gas will leak out of the sphere will depend on the number of times the molecules of that gas strike the side of the sphere. It is found that the mixture of gases leaking from the hole has many more molecules of gas X in it than molecules of gas Y.

14. From this observation one can conclude that:

    (a) The hole is not big enough for the heavy gas Y molecules to pass through

    (b) Gas X molecules have a faster average molecular speed than gas Y molecules

Go on to the next page

(c) The molecules of gas X have a lower kinetic energy than gas Y molecules

(d) The temperature of the two gases could not possibly have been the same

(e) None of the above is a correct conclusion

15. A second conclusion one can draw from this observation is that:

(a) The molecules of gas X have a higher average kinetic energy than gas Y molecules

(b) The weight of each gas X molecule is greater than that of each gas Y molecule

(c) The weight of each gas X molecule is less than that of each gas Y molecule

(d) Gas X molecules have a slower average speed than gas Y molecules

(e) Gas Y molecules would diffuse through another gas at a faster rate than gas X molecules

16. If you wished to separate two gases by the process of diffusion, you must choose two gases with molecules which have:

(a) different volumes

(b) different temperatures

(c) different weights

(d) all of the properties in a, b, and c

(e) none of the properties in a, b, and c

17. A student had a container of a mixture of laughing gas, tear gas, and a deadly poisonous gas. He tried to separate them by diffusing the mixture through a tube filled with air. The weight of a tear gas molecule is much greater than the weight of a laughing gas molecule. The poisonous gas has a lesser average speed than the tear gas. He made the mistake of detecting the gases at the other end of the pipe by smelling for them as they arrived. If each gas did its job, we can conclude:

(a) He never got past the first gas

(b) He laughed, then cried, then died

(c) He cried, then died

(d) He laughed, then died

(e) You can't tell what would happen when he smelled the first gas to arrive

Go on to the next page

Diffusion Test (continued)

18. The gas which arrived at the end of the pipe first in question 17:
    (a) Had the greatest kinetic energy
    (b) Had the lightest molecules
    (c) Was at the lowest temperature
    (d) Had the slowest rate of diffusion
    (e) Had the slowest moving molecules

19. The over-all conclusion in this passage was:
    (a) Temperature is a measure of the average speed of molecules
    (b) Lighter molecules can be separated from the heavier molecules by allowing a mixture of the gases to diffuse through air
    (c) Some molecules are lighter than other molecules and the lighter molecules diffuse faster
    (d) The molecules of the lighter gas differ in a number of respects from the molecules of the heavier gas
    (e) The gas which has the fastest rate of diffusion has the weakest attractive forces among its molecules

20. When the mixture of two gases diffuse through the air in the pipe:
    (a) the molecules of the two gases constantly collide with each other, but not with the air molecules
    (b) the molecules of the gases travel the shortest possible distance from one end of the pipe to the other end
    (c) some of the heavy molecules may travel along the pipe as fast as some of the light molecules
    (d) the molecules which reached the end of the pipe first were at no time moving at a speed less than the average speed along the way
    (e) the molecules would diffuse faster through the pipe if the pressure in the pipe was greater

STOP: Do not turn this page until you are asked to do so. If you are finished before time is called, check your work.

E X P E R I M E N T   II

SCENARIO: COMPRESSION SIMULATION

The demonstration was opened with the comment, "I would like to show you that if a gas is compressed enough it will turn into a liquid." "This tank represents a cylinder into which some gas molecules will be placed." The balls were placed in the four corners of the tank and one was placed in the middle.

"These styrofoam balls represent molecules in the gaseous state. "When they are far apart as they are now, the attractive force between the balls is negligible." The piston was then pushed along the top of the tank pushing the balls closer together.

"This board represents a piston. Pushing it along the top of the tank represents compressing a gas in a cylinder. Notice the decreasing space the balls occupy." Soon some of the balls started to attract each other. "Observe that as the balls move closer together, they begin to attract each other because when they are close enough the attractive forces among the balls become strong enough to pull them together. In the same way, when a gas is compressed, the molecules move closer together and begin to attract each other to form clusters of molecules."

The "piston" was then pushed along the tank further until all the balls attracted each other and formed into one conglomerate mass.

"Notice that as the compression is continued, the balls move closer and closer together until they begin to form large clusters of

molecules. These larger clusters are like droplets of liquid. When they become large enough they can no longer be suspended by the gas and they fall out of the gas, or precipitate." To demonstrate the concept of critical temperature the following explanation was used. The demonstrator took two of the balls and set them apart at a distance such that they attracted each other and formed a dyad.

"Notice that if the balls are placed a distance of six inches from each other they will attract each other. However, molecules do not remain in one place but are in constant motion. Their motion is dependent on the temperature of the gas. The higher the temperature, the faster the molecules move. Now let us take these two balls and start them in a slow motion parallel to each other at the same distance as before. Again we observe the molecules come together. This time we will repeat the procedure at the same distance and direction but we will make the balls move at a greater speed."

The balls were then sent parallel to each other at a much greater velocity. "Notice that when the speed of the balls is fast enough the balls attract each other but they by-pass each other because the attractive force is not great enough to bring them together at these high speeds. In the same way, molecules can not be moving too fast or the attractive forces will not be strong enough to hold them together. Since the speed of molecules is indicated by their temperature, we can insure low speed by having low temperatures. For each gas there is a temperature, called the critical temperature, above which a gas will not condense under compression because the molecules are

moving too fast. In other words, above the critical temperature the molecules will not be held together by the attractive forces because they are moving too fast."

At this point the balls were again placed in the tank as originally and the piston was again moved across the tank until the balls all clustered. No commentary accompanied this second repetition except the introductory comment, "Let us once more observe the compression process." Students were then asked if they had any questions concerning the demonstration or the process of liquification of a gas upon compression. The absence of further questions was taken as an indication that students had understood the simulation.

SCENARIO: DIFFUSION SIMULATION

When students were seated ready to begin their science period the author said,

1. "I would like you to participate with me in an experiment today. I am going to call out your name and a number. Those of you who receive odd numbers are asked to leave the room for about five minutes."
   After those with odd numbers had left, the demonstration was opened with the comment, "I am going to demonstrate to you how two gases may be separated by diffusing them through air."

2. The light of the overhead projector was then turned on. "I have here a glass box into which I have placed thirty glass beads and thirty lead balls all of which as you can see on the screen are the same size. The circles on the screen with the light spot in the middle are glass beads whereas the solid circles are lead balls. The lead balls are much heavier than the glass beads. The larger circles you can see equally spaced on the screen are studs which project from the top to the bottom glass plates.

3. The motor was then turned on so the DC began to oscillate back and forth causing the balls and beads to be struck by the metal studs. The beads and balls moved in an apparently random fashion.

The motor was then turned off and the DC was tilted causing the beads and balls to roll toward the closed end of the DC.

"As I said before, I want to use this apparatus to demonstrate the diffusion of two gases through air. Let the glass beads represent the molecules of one gas and let the lead balls represent the molecules of the other gas. The glass beads being the lighter spheres will represent the molecules of a light gas while the heavier lead balls will represent the molecules of a heavier gas. The metal studs will represent air molecules and the glass box will represent a pipe through which we will diffuse the two gases. Notice that since all the spheres receive their kinetic energy by virtue of the motion of the glass box, the lead balls will have the same average kinetic energy as the glass beads. I am going to turn on the motor and after ten seconds we will count the number of each kind of sphere which comes out the open end of the glass box."

4. The motor was then started and after ten seconds was stopped. The number of each kind of sphere was recorded on a table on the blackboard. The spheres which had exited were returned to the chamber after each trail and the DC was tilted to cause all the spheres to roll to the closed end of the DC, before beginning the next trial. This procedure was repeated four times. Each time the analogous relations between the glass beads and light molecules; lead balls and heavy molecules; and metal studs and air molecules were explicitly pointed out. The results of ten previous trials were then listed on the blackboard.

5. To evaluate whether students had made the analogy correctly the following question was asked; "Two gases, one having light molecules and one having heavy molecules were allowed to diffuse through air in a pipe. Raise your hand if you think the lighter molecules would first reach the end of the pipe in greater numbers?" It was noted that all students present had raised their hands.

6. The simulation was terminated at this point and those students who had been sent out of the room were recalled.

E X P E R I M E N T III

CLASSIFICATION OF MATTER TEST

Time: 15 minutes

Number of Questions: 15

Answers: Indicate all your answers on the SPECIAL ANSWER SHEET provided. Use an HB LEAD PENCIL only. Do not use ink or ball point pen. MAKE A HEAVY BLACK MARK TO FILL THE SPACE BETWEEN THE PAIR OF LINES. If you change your mind, erase your first mark completely. Do not make stray marks on the answer sheet.

BLACKEN ONE SPACE ONLY for each question.

Read the question carefully. Remember, the words used in the questions are used in their SCIENTIFIC sense.

Some questions ask you to select the answer which is FALSE or the one which is the EXCEPTION.

<u>EXAMPLE</u>: 1. All of the following are boys' names <u>except</u>:

(a) Jim
(b) John
(c) Jane
(d) Jack

Sample Answer:

1. A 1 B 2 C 3 D 4 E 5

For each question, darken the space corresponding to the word or phrase which <u>BEST</u> answers the question or <u>BEST</u> completes the sentence.

You may not use the reading passage during the test.

There is no penalty for guessing.

PLEASE DO NOT TURN THIS PAGE UNTIL YOU ARE ASKED TO DO SO

THE CLASSIFICATION OF MATTER (T-1)

The world, and everything in it and on it--including you--are made of matter. But what is matter? You may be familiar with the idea that matter is "that which has weight and occupies volume." Such a definition really does not add much to your understanding of what matter is made of.

In the following paragraphs you will learn about the classification system of matter.

All matter is made up of very tiny units. These units are called CHEMICAL UNITS.

Two different kinds of chemical units you have probably heard about are ATOMS and MOLECULES.

The chemical units which make up any one piece (sample) of matter can be either the same or different. If the chemical units of a sample are all the same, then the sample is called a SUBSTANCE. Substances are referred to as <u>pure</u> forms of matter. If, on the other hand, there is more than one kind of chemical unit in a sample, the sample is referred to as a MIXTURE. Mixtures are referred to as <u>impure</u> forms of matter. Notice the special meaning chemists have for the word "substances." A "substance" is a <u>pure</u> sample of matter. You might think of a substance as being the opposite of a mixture.

Nearly all samples of matter which are found in nature are mixtures. That is, they contain more than one kind of chemical unit. Such samples are very hard to study chemically because they have different kinds of chemicals in them. Therefore, in the study of matter it is easier to begin with the study of substances--(samples of matter in which all the chemical units are exactly the same).

ELEMENTS

If all the chemical units of a sample of a substance are ATOMS, then the sample of the substance is called an ELEMENT. In other words, an ELEMENT is a sample of matter in which all the chemical units are atoms and all the atoms are exactly the same.

Since there are 104 different kinds of atoms, there are 104 different elements. Elements are given their name because they are composed of the elementary (or simplest) chemical units (atoms). Chemists say atoms are the simplest units of matter because they cannot break an atom down into any simpler units by any ordinary energy sources; (i.e. heat, light, electricity, mechanical, etc.). Each element has a kind of atom which is different from the atoms of every other element. No two elements have the same kinds of atoms.

COMPOUNDS

As you know, there are more than 104 different kinds of substances in the world, in fact there are millions of different kinds of substances (i.e. samples of matter which have the same kinds of chemical units throughout). The answer to the existence of so many different kinds of substances lies in the fact that different kinds of atoms can hook up with each other (we say can "combine chemically") to form new substances called COMPOUNDS. The chemical units of compounds are called MOLECULES. Therefore, a compound is a sample of matter in which all the chemical units (molecules) are exactly the same.

Molecules are chemical units which are composed of <u>two or more</u> different kinds of atoms.

Something very odd happens when atoms combine to form molecules. The atoms lose their properties (except their weight) and the molecule formed has a set of properties which only it has, and which neither of the atoms had. In other words, if two atoms A and B combine chemically

to form a molecule AB the molecule AB will not look like, taste like, or behave like either of the atoms A or B did before they combined chemically with each other. The molecule AB has a special set of properties which is different from the set of properties of every other molecule or atom. That is, each molecule has a unique set of properties.

Elements differ from compounds in one very important way. The chemical units of elements (atoms) are the simplest units of matter and cannot be broken down into any simpler units. On the other hand, the chemical units of compounds (molecules) are made up of two or more different kinds of atoms and therefore can be broken down into individual atoms. This gives us a way of telling an element from a compound. If a compound is heated to a high enough temperature, eventually it will break down into the atoms which make it up; whereas atoms of elements will not break down into simpler substances.

In summary, matter is classified into elements, compounds and mixtures. The basic chemical unit of an element is an atom. The basic chemical unit of a compound is a molecule. Compounds and elements are given the name substances because they are pure forms of matter. Mixtures, on the other hand, are made up of two or more different kinds of chemical units and are called impure forms of matter. That is the way chemists classify matter.

THE CLASSIFICATION OF MATTER - A COMPARIS

The classification of matter can be thought of as being similar to the letters and words of the English language.

The letters of the alphabet are the basic building blocks of a language, just as the atoms are the basic building blocks of matter. In short, the "letters' of matter are called atoms. Furthermore, just as letters may be grouped together to form words, atoms may combine chemically to form molecules. That is, the "words" of matter are called molecules. Molecules behave as a single unit just as words do.

We can use this letter-word comparison to clarify the classification of matter. The idea of a substance can be explained by considering sets in which all of the members are identical. That is, they are "pure" sets. A pure set of atoms is called an element. This can be compared to a pure set of letters in which all of the letters are identical. For example, (n,n,n,n,n,n,,,,,,).

A pure set of molecules is called a compound. This can be compared to a pure set of words in which all of the words are identical. For example, (yes, yes, yes....).

Now you can see substances (pure sets) can be divided into two classes:

(a) those that have atoms which are all identical (pure letter sets)--elements, and
(b) those that have molecules which are all identical (pure word sets)--compounds.

Mixtures, on the other hand, can be thought of as impure sets. Our letter-word comparison tells us we can have mixtures of:

(a) letters (atoms) e.g. (K, Z, A, Y ...),
(b) words (molecules) e.g. (Yes, cow, no, up ...), and
(c) words and letters (atoms and molecules) e.g. (K, boat, Y, ski ...).

Just as when letters are combined to form words they no longer keep their individual meaning, so too when atoms combine chemically to

form compounds, the individual atoms lose their properties. For example, when "I" and "N" are put together to form the word "IN", they take on new meaning and lose their individual meanings. Furthermore, the meaning of the word "IN" is unique just as the properties of a compound are unique to that compound.

It should be remembered that a word can be broken down into its individual letters just as a molecule can be broken down into its individual atoms.

As you can see, it is helpful to remember, "letters are to atoms as words are to molecules" when you classify matter.

CLASSIFICATION OF MATTER TEST

1. A substance is:
   (a) any sample of matter
   (b) an impure sample of matter
   (c) a pure sample of matter
   (d) a chemical unit

2. The main difference between elements and mixtures is:
   (a) elements have atoms whereas mixtures do not
   (b) mixtures have no chemical units whereas elements do
   (c) elements are substances whereas mixtures are not
   (d) elements can combine to form molecules whereas mixtures are molecules

3. A substance which cannot be broken down into simpler substances is a(n):
   (a) molecule
   (b) mixture
   (c) compound
   (d) element

4. An impure sample of matter is called a(n):
   (a) mixture
   (b) element
   (c) compound
   (d) molecule

5. Two shiny elements combine together to form a compound. Which of the following statements is the best prediction of what the compound will look like:
   (a) the compound will not be shiny
   (b) the compound will be shiny
   (c) the compound will be partly shiny and partly dull
   (d) the compound's appearance cannot be predicted

6. The chemical unit of a compound is:
   (a) a molecule
   (b) a substance
   (c) a volume
   (d) an atom

Classification of Matter Test (continued)

7. The gas helium is made up of atoms which are all chemically the same. The dry cleaning liquid carbon tetrachloride is made up of molecules which are all chemically the same and which contain carbon and chlorine atoms.
Which of the following statements is false?
   (a) helium is an element
   (b) carbon tetrachloride is a mixture
   (c) helium is a substance
   (d) carbon tetrachloride is a compound

8. Which of the following would not be classified as matter?
   (a) a rock
   (b) molecules
   (c) mixtures
   (d) democracy

9. Two different kinds of chemical units are:
   (a) elements and substances
   (b) atoms and molecules
   (c) weight and volume
   (d) colour and taste

10. Which of the following would have more than one kind of chemical unit:
   (a) an element
   (b) a compound
   (c) a mixture
   (d) a substance

11. Since there are 104 different kinds of atoms, there are exactly 104 different:
   (a) compounds
   (b) mixtures
   (c) substances
   (d) elements

12. In an experiment a white solid substance was heated to form a yellow gas and a green solid. Which of the following statements is a correct conclusion to make?
   (a) the green solid is an element
   (b) the yellow gas was a compound
   (c) the white solid may have been a mixture
   (d) the white solid was a compound

Classification of Matter Test (continued)

13. In an experiment a yellow solid substance was heated gently producing a colourless liquid as well as a white solid. The original solid:

    (a) was an element
    (b) was a compound
    (c) was a mixture
    (d) may have been more than one of the choices a, b or c

14. In an experiment a solid sample is light brown in colour with dark blue lines running throughout it. When it was heated, colourless gases and a black solid were formed. The original sample:

    (a) was an element
    (b) was a compound
    (c) was a mixture
    (d) may have been more than one of the choices a, b or c

15. In an experiment a pale yellow-green gas was discovered and analyzed. It was found that there was only one kind of atom in this gas. The pale yellow-green gas:

    (a) was an element
    (b) was a compound
    (c) was a mixture
    (d) may have been more than one of the choices a, b or c

APPENDIX B

TEST DATA

TABLE 20

Items Analysis for Phase Change Criterion and Analogy Tests: Argument Rank Six

Experiment I

A. Criterion Test*

Item Number	Difficulty		Biserial Correlation Coefficient		Reliability Index	
	Grade 8	Grade 10	Grade 8	Grade 10	Grade 8	Grade 10
1	.62	.83	.64	.38	.31	.14
2	.34	.70	.55	.48	.26	.22
3	.38	.62	.36	.61	.18	.30
4	.50	.60	.57	.51	.28	.25
5	.67	.92	.70	.65	.33	.18
6	.54	.79	.63	.61	.31	.25
7	.32	.39	.19	.28	.09	.13
8	.55	.80	.74	.64	.37	.26
9	.56	.81	.65	.45	.32	.18
10	.36	.68	.69	.54	.33	.25
11	.31	.68	.65	.69	.30	.32
12	.26	.58	.51	.51	.22	.25
13	.41	.75	.64	.61	.32	.26
14	.37	.71	.51	.72	.25	.33
15	.31	.56	.43	.62	.20	.31
16	.50	.69	.69	.72	.34	.33
17	.39	.53	.62	.47	.30	.24
18	.35	.59	.70	.54	.33	.27
19	.46	.69	.62	.55	.31	.26
20	.30	.35	.10	.47	.05	.22

* N = 136 for grade 8; N = 218 for grade 10

Table 20 (continued)

B. Analogy Test**

Item Number	Difficulty		Biserial Correlation Coefficient		Reliability Index	
	Grade 8	Grade 10	Grade 8	Grade 10	Grade 8	Grade 10
1	.64	.85	.71	.82	.34	.30
2	.60	.82	.58	.97	.28	.37
3	.67	.73	.64	.86	.30	.38
4	.63	.76	.67	.56	.33	.24
5	.51	.89	.61	1.04	.31	.33
6	.45	.78	.69	.63	.34	.26
7	.66	.88	.73	1.15	.34	.31
8	.54	.79	.65	.78	.32	.32

**N = 95 for grade 8; N = 144 for grade 10

TABLE 21

Items Analysis for Compression Criterion and Analogy Tests: Argument Rank Six

Experiment I

A. Criterion Test*

Item Number	Difficulty		Biserial Correlation Coefficient		Reliability Index	
	Grade 8	Grade 10	Grade 8	Grade 10	Grade 8	Grade 10
1	.33	.56	.39	.41	.18	.21
2	.79	.92	.47	.79	.19	.21
3	.59	.80	.30	.75	.15	.30
4	.12	.22	.11	.49	.03	.20
5	.28	.62	.51	.67	.23	.33
6	.42	.72	.46	.61	.22	.28
7	.57	.78	.66	.64	.33	.27
8	.50	.73	.75	.64	.37	.28
9	.31	.57	.60	.35	.28	.17
10	.31	.67	.55	.42	.25	.20
11	.39	.70	.60	.59	.30	.27
12	.40	.78	.56	.67	.28	.28
13	.32	.54	.52	.34	.24	.17
14	.29	.45	.41	.53	.19	.26
15	.24	.43	.34	.53	.15	.26
16	.28	.42	.50	.59	.23	.29
17	.40	.68	.58	.61	.28	.29
18	.43	.65	.54	.51	.27	.24
19	.44	.66	.48	.40	.24	.19
20	.16	.44	.60	.45	.22	.22

* N = 135 for grade 8; N = 204 for grade 10

Table 21 (continued)

B. Analogy Test**

Item Number	Difficulty		Biserial Correlation Coefficient		Reliability Index	
	Grade 8	Grade 10	Grade 8	Grade 10	Grade 8	Grade 10
1	.52	.95	.65	.48	.32	.10
2	.45	.95	.65	.97	.32	.22
3	.62	.64	.58	.62	.28	.30
4	.73	.77	.68	.76	.30	.32
5	.29	.82	.62	.87	.28	.33
6	.41	.75	.87	.64	.43	.28
7	.55	.75	.76	.71	.39	.31
8	.50	.71	.57	.70	.39	.32

** N = 101 for grade 8; N = 146 for grade 10

TABLE 22

Items Analysis for Diffusion Criterion and Analogy Tests:
Argument Rank Six

Experiment I

A. Criterion Test*

Item Number	Difficulty		Biserial Correlation Coefficient		Reliability Index	
	Grade 8	Grade 10	Grade 8	Grade 10	Grade 8	Grade 10
1	.53	.64	.43	.41	.21	.20
2	.39	.63	.43	.66	.21	.32
3	.51	.73	.38	.50	.19	.22
4	.38	.65	.53	.71	.24	.34
5	.49	.64	.66	.72	.33	.35
6	.55	.79	.67	.79	.33	.32
7	.43	.68	.67	.71	.33	.33
8	.35	.54	.65	.69	.31	.35
9	.44	.76	.62	.56	.31	.24
10	.32	.58	.49	.52	.23	.26
11	.44	.56	.44	.38	.22	.19
12	.37	.49	.30	.49	.15	.25
13	.44	.73	.52	.79	.26	.35
14	.50	.74	.46	.63	.23	.28
15	.37	.58	.64	.75	.31	.37
16	.39	.54	.54	.62	.26	.31
17	.43	.60	.55	.58	.27	.28
18	.43	.71	.60	.67	.30	.31
19	.39	.42	.39	.27	.19	.13
20	.26	.33	.12	.54	.05	.25

*N = 123 for grade 8; N = 212 for grade 10

Table 22 (continued)

B. Analogy Test**

Item Number	Difficulty		Biserial Correlation Coefficient		Reliability Index	
	Grade 8	Grade 10	Grade 8	Grade 10	Grade 8	Grade 10
1	.59	.49	.79	.57	.39	.29
2	.56	.57	.65	.75	.32	.37
3	.40	.77	.48	.82	.24	.35
4	.44	.82	.61	.64	.31	.25
5	.51	.64	.65	.63	.33	.30
6	.61	.56	.60	.80	.29	.40
7	.41	.74	.72	.86	.36	.38
8	.44	.79	.69	.86	.34	.35

** N = 88 for grade 8; N = 146 for grade 10

APPENDIX C

EXPERIMENTAL DATA

EXPERIMENT I - VERBAL ANALOGIES

The data for this experiment is presented in Tables 23 and 24 under four columns: A,B,C,D. Column A contains a three digit number indicating the topic, argument rank, and treatment cell number. The first digit indicates the topic of the scientific explanation. The topic and its associated digit are: Phase Change = 1, Compression = 2, Diffusion = 3. The second digit indicates the argument rank of the scientific explanation. Argument rank three and argument rank six are associated with the digits three and six, respectively. The third digit of the number in column A indicates the treatment number: Pre - 1, Post - 2, Within - 3, Side x Side - 4, Advance Analogy - 5, Advance KMT - 6, and Control - 7. The digit in Column B indicates the sex of the subject: male = 1, female = 2. The digit in column C indicates the score the individual achieved on the associated analogy test. The analogy test score reported does not include the two items used in the test to determine whether the subject knew how to respond to analogy items. Hence, the total possible score is six for argument rank three passages and eight for argument rank six passages. The numerals under column D indicate the score on the criterion test. The total possible score is sixteen and twenty for argument rank three and argument rank six scientific explanations, respectively.

TABLE 23

Analogy and Criterion Tests' Scores

Experiment I - Verbal Analogies

Grade 8

A	B	C	D	A	B	C	D
131	2	5	11	132	1	5	9
	2	3	8		1	3	4
	2	5	6		1	3	7
	2	4	8		1	4	10
	2	4	3		1	5	9
	2	3	9	133	2	3	7
	2	2	4		2	3	4
	2	5	13		2	2	7
	2	4	12		2	4	7
	2	5	12		2	1	9
	1	5	5		2	2	6
	1	4	6		2	2	6
	1	5	7		2	4	5
	1	6	7		2	5	8
	1	5	13		2	2	7
	1	5	9		2	5	7
	1	3	9		1	2	7
	1	6	9		1	3	6
	1	6	13		1	6	12
	1	0	5		1	6	12
	1	2	1		1	6	11
132	2	2	2		1	6	7
	2	3	5		1	6	11
	2	6	9		1	2	9
	2	6	11		1	5	4
	2	5	11	134	2	3	6
	2	4	3		2	3	4
	2	4	10		2	6	3
	2	6	8		6	6	10
	2	5	4		2	4	6
	2	5	6		2	1	4
	2	5	9		2	6	7
	2	2	4		2	5	10
	1	5	9		2	2	12
	1	5	12		2	3	8
	1	4	14		2	4	5
	1	6	8		1	1	4

Table 23 (continued)

A	B	C	D
134	1	2	6
	1	1	8
	1	5	13
	1	3	8
	1	4	12
	1	5	6
	1	6	9
	1	0	3
	1	3	9
135	2	3	3
	2	3	10
	2	2	6
	2	3	9
	2	3	7
	2	6	12
	2	3	5
	2	6	13
	1	0	6
	1	4	5
	1	5	10
	1	5	12
	1	2	7
136	2	-	5
	2	-	6
	2	-	10
	2	-	8
	2	-	9
	2	-	9
	2	-	6
	2	-	7
	2	-	4
	1	-	13
	1	-	7
	1	-	8
	1	-	8
	1	-	8
137	2	-	7
	2	-	4
	2	-	8
	2	-	4
	2	-	8
	2	-	10
	2	-	4
	2	-	7
	2 -	-	5
137	2	-	7
	2	-	6
	2	-	6
	2	-	11
	1	-	9
	1	-	4
	1	-	4
	1	-	5
	1	-	11
	1	-	7
	1	-	7
	1	-	4
	1	-	4
	1	-	3
231	2	5	8
	2	6	10
	2	3	9
	2	4	7
	2	6	9
	2	5	8
	2	3	7
	2	3	6
	2	4	5
	2	4	5
	1	5	6
	1	3	3
	1	3	1
	1	5	8
	1	4	7
	1	2	5
	1	2	1
	1	1	4
	1	3	7
	1	5	6
	2	2	2
	2	2	5
	2	4	10
	2	3	7
	2	5	3
	2	3	6
	2	3	4
	2	1	3
232	2	3	6
	2	3	9
	2	3	6

Table 23(continued)

A	B	C	D	A	B	C	D
232	2	0	5	235	2	6	9
	1	2	3		2	6	7
	1	4	1		2	4	9
	1	5	7		2	4	10
	1	5	4		2	3	3
	1	2	8		2	3	12
	1	5	10		1	4	8
	1	4	10		1	5	10
	1	2	10		1	4	11
233	2	5	3		1	3	9
	2	5	10		1	4	4
	2	5	12		1	4	6
	2	5	4		1	2	2
	2	5	7		1	2	6
	2	3	9		1	3	7
	2	2	1		1	4	5
	2	4	5	236	2	-	8
	2	5	6		2	-	8
	1	5	8		2	-	12
	1	3	5		2	-	6
	k	5	7		2	-	6
	k	2	8		2	-	7
	1	1	4		2	-	11
	k	2	7		1	-	9
	1	4	11		1	-	6
	1	5	7		1	-	8
	1	4	5		1	-	7
	1	3	5		1	-	5
	1	4	7		1	-	11
234	2	5	11		1	-	8
	2	3	10	237	2	-	3
	2	2	5		2	-	8
	2	4	4		2	-	5
	2	3	8		2	-	6
	2	1	4		2	-	3
	2	1	2		2	-	7
	2	3	7		2	-	2
	2	3	3		2	-	5
	2	1	7		2	-	5
	1	4	7		2	-	9
	1	5	10		1	-	11
	1	4	4		1	-	1
	1	5	10		1	-	5
	1	3	4		1	-	4
	1	5	7		1	-	8
	1	6	9		1	-	10
	1	4	11		1	-	2
	1	3	5		1	-	5

Table 23(continued)

A	B	C	D	A	B	C	D
237	1	-	11	333	2	5	12
	1	-	3		2	4	5
	1	-	6		2	2	4
331	2	1	5		2	0	4
	2	5	8		2	0	5
	2	1	5		2	1	3
	2	5	8		2	3	7
	2	2	4		2	3	6
	2	6	13		1	2	1
	2	2	6		1	0	2
	2	2	5		1	1	3
	2	2	14		1	1	4
	2	3	2		1	3	5
	1	1	4		1	3	7
	1	5	8		1	1	8
	1	5	7		1	2	6
	1	2	4	334	2	2	6
	1	3	4		2	2	4
	1	5	6		2	2	7
	1	4	7		2	3	4
	1	1	3		2	4	8
	1	1	2		2	4	11
332	2	3	3		2	1	9
	2	2	7		2	5	8
	2	2	7		2	5	7
	2	4	5		1	0	0
	2	3	4		1	1	4
	2	4	6		1	1	9
	2	4	5		1	0	6
	2	0	4		1	2	5
	2	1	4		1	5	11
	2	2	5		1	1	4
	1	1	5		1	3	6
	1	3	6		1	4	8
	1	1	8	335	2	4	7
	1	1	6		2	4	7
	1	4	9		2	2	4
	1	5	8		2	3	8
	1	4	9		2	2	13
	1	2	1		2	2	6
	1	0	4		2	2	5
	1	2	7		1	2	10
333	2	5	9		1	3	6
	2	2	6		1	2	7
	2	0	6		1	3	7

Table 23 (continued)

A	B	C	D
335	1	3	5
	1	4	14
	1	2	10
	1	2	4
336	2	-	7
	2	-	7
	2	-	5
	2	-	6
	2	-	4
	2	-	6
	2	-	6
	2	-	12
	2	-	7
	1	-	11
	1	-	7
	1	-	8
	1	-	7
	1	-	9
	1	-	3
	1	-	4
337	2	-	4
	2	-	9
	2	-	6
	2	-	7
	2	-	7
	2	-	11
	2	-	4
	2	-	7
	2	-	7
	2	-	14
	1	-	3
	1	-	3
	1	-	3
	1	-	7
	1	-	9
	1	-	15
	1	-	8
	1	-	5
	1	-	5
161	1	2	2
	1	8	14
	1	7	10
	1	2	4
	1	5	7

A	B	C	D
161	1	3	0
	1	3	4
	1	1	1
	2	6	18
	2	3	5
	2	3	7
	2	6	6
	2	4	5
	2	5	11
	2	5	6
	2	2	6
	2	5	2
	2	7	13
162	1	4	17
	1	8	15
	1	7	5
	1	8	10
	1	7	13
	1	2	5
	1	4	13
	1	7	3
	1	6	12
	1	8	11
	2	4	5
	2	6	4
	2	3	6
	2	4	3
	2	6	7
	2	1	8
	2	5	7
	2	5	7
	2	5	8
163	1	7	14
	1	5	8
	1	8	7
	1	4	4
	1	4	10
	1	4	7
	1	2	5
	1	4	7
	1	4	4
	1	5	4
	2	0	8
	2	2	4
	2	3	6

Table 23 (continued)

A	B	C	D	A	B	C	D
163	2	3	6	166	1	-	5
	2	7	14		1	-	15
	2	4	11		1	-	7
	2	6	11		1	-	7
	2	4	6		1	-	5
	2	8	18		1	-	6
	2	3	5		1	-	11
	2	4	2		1	-	15
164	1	3	6		1	-	7
	1	8	13		2	-	4
	1	4	4		2	-	8
	1	3	5		2	-	9
	1	4	2		2	-	11
	1	6	4		2	-	11
	1	8	15		2		14
	1	3	6		2	-	9
	1	4	4		2	-	10
	2	4	12		2	-	16
	2	3	4	167	1	-	15
	2	7	9		1	-	15
	2	3	6		1	-	15
	2	6	9		1	-	9
	2	3	5		1	-	4
	2	2	7		1	-	8
	2	4	6		1	-	10
	2	6	7		1	-	9
	2	3	6		1	-	11
	2	1	7		1	-	13
	1	4	1		2	-	10
165	1	2	13		2	-	14
	1	6	11		2	-	14
	1	7	10		2	-	12
	1	5	8		2	-	16
	1	7	10		2	-	5
	1	10	10		2	-	12
	2	4	9		2	-	11
	2	2	4		2	-	2
	2	3	4		2	-	5
	2	8	10		2	-	8
	2	5	10		2	-	10
	2	3	3		2	-	10
	2	6	2	261	1	5	14
	2	6	8		1	6	7
	2	8	15		1	3	6
	2	7	17				
	2	4	0				

Table 23 (continued)

A	B	C	D
261	1	8	12
	1	1	3
	1	1	10
	1	5	10
	1	2	9
	1	6	13
	1	8	14
	2	2	8
	2	5	6
	2	5	10
	2	4	12
	2	1	5
	2	2	6
	2	2	1
	2	5	7
	2	5	2
	2	2	5
	2	6	9
262	1	1	2
	1	2	8
	1	1	6
	1	5	3
	1	7	6
	1	6	5
	1	6	11
	1	0	7
	1	3	6
	1	5	7
	2	1	7
	2	4	8
	2	4	4
	2	6	13
	2	2	10
	2	4	3
	2	4	7
	2	3	6
	2	3	2
263	1	4	5
	1	4	0
	1	3	5
	1	3	5
	1	1	5
	1	3	2
	1	6	4
	1	4	3
263	1	3	8
	2	6	5
	2	4	4
	2	1	8
	2	2	6
	2	3	6
	2	5	13
	2	5	13
	2	4	4
	2	8	9
	2	7	13
264	1	6	13
	1	5	11
	1	3	6
	1	7	8
	1	6	8
	1	2	7
	1	2	8
	1	7	6
	2	5	12
	2	3	17
	2	5	15
	2	1	6
	2	6	10
	2	5	7
	2	6	4
	2	2	7
	2	3	6
	2	1	3
265	1	3	5
	1	8	15
	1	0	10
	1	4	10
	1	2	4
	1	2	5
	1	4	7
	1	6	7
	2	3	14
	2	6	12
	2	3	6
	2	5	7
	2	8	18
	2	4	7
	2	4	5
	2	6	6

Table 23 (continued)

A	B	C	D
	2	4	4
	2	7	10
	2	7	7
	2	2	3
266	1	5	10
	1	5	8
	1	3	4
	1	-	3
	1	-	12
	1	-	8
	1	-	14
	2	-	11
	2	-	4
	2	-	4
	2	-	12
	2	-	14
	2	-	7
	2	-	4
	2	-	14
	2	-	5
	2	-	5
267	1	-	14
	1	-	8
	1	-	8
	1	-	9
	1	-	8
	1	-	4
	1	-	14
	1	-	0
	1	-	7
	2	-	11
	2	-	6
	2	-	9
	2	-	3
	2	-	12
	2	-	9
	2	-	9
	2	-	3
	2	-	7
	2	-	6
361	1	5	9
	1	6	11
	1	1	6
	1	5	5

A	B	C	D
361	1	3	1
	1	2	6
	1	6	16
	2	2	5
	2	1	7
	2	1	4
	2	2	6
	2	1	4
	2	4	2
	2	5	11
	2	3	3
	2	7	11
362	1	4	13
	1	3	8
	1	1	10
	1	3	4
	1	2	5
	1	1	3
	1	8	13
	1	3	8
	2	4	6
	2	7	17
	2	4	6
	2	6	7
	2	5	13
	2	3	12
	2	5	6
	2	4	10
	2	8	13
363	1	6	9
	1	6	9
	1	5	19
	1	0	6
	1	1	4
	1	2	9
	1	1	5
	1	4	10
	2	7	8
	2	6	12
	2	4	10
	2	4	5
	2	7	11
	2	3	6
	2	5	9
	2	6	11

Table 23 (continued)

A	B	C	D
364	1	6	11
	1	6	5
	1	8	7
	1	0	10
	1	2	5
	1	3	2
	1	5	7
	1	7	10
	1	6	6
	2	5	7
	2	2	4
	2	2	4
	2	2	2
	2	3	4
	2	4	15
	2	2	5
	2	6	13
365	1	3	6
	1	6	8
	1	4	3
	1	6	11
	1	3	6
	1	5	10
	1	3	4
	1	2	5
	1	8	17
	1	0	7
	2	0	2
	2	5	7
	2	3	5
	2	7	9
	2	5	7
	2	3	5
	2	2	4
	2	4	6
	2	0	19
366	1	-	10
	1	-	12
	1	-	7
	1	-	10
	1	-	10
	1	-	8
	1	-	9
	2	-	10
	2	-	7

A	B	C	D
336	2	-	9
	2	-	5
	2	-	7
	2	-	15
	2	-	3
367	1	-	8
	1	-	10
	1	-	4
	1	-	5
	1	-	15
	1	-	7
	1	-	13
	1	-	5
	2	-	10
	2	-	8
	2	-	12
	2	-	10
	2	-	10
	2	-	6
	2	-	9
	2	-	9
	2	-	5
	2	-	10
	2	-	9

TABLE 24

Analogy and Criterion Tests' Scores

Experiment I

Grade 10

A	B	C	D	A	B	C	D	A	B	C	D
131	2	6	11	132	2	5	13	133	1	6	13
	2	6	13		2	6	13		1	3	12
	2	6	12		2	5	9		1	3	10
	2	3	9		2	2	11		1	2	12
	2	6	12		2	4	7		1	6	11
	2	6	9		2	4	12		1	4	10
	2	6	9		1	6	13		1	5	9
	2	6	10		1	6	11	134	2	6	14
	2	6	12		1	5	13		2	2	6
	2	4	9		1	5	13		2	5	11
	2	2	2		1	6	7		2	4	6
	2	6	13		1	6	12		2	5	8
	2	2	13		1	4	3		2	4	12
	2	5	12		1	4	3		2	3	5
	2	3	7		1	6	8		2	5	13
	1	3	10		1	4	12		2	6	11
	1	6	15		1	6	11		2	6	14
	1	6	13	133	2	5	13		2	2	10
	1	6	13		2	6	12		2	4	10
	1	4	5		2	6	15		2	4	6
	1	6	12		2	4	13		2	5	11
	1	4	11		2	6	10		2	4	6
	1	5	13		2	5	11		2	5	6
	1	5	12		2	4	8		2	5	13
	1	5	11		2	6	8		1	3	8
	1	5	11		2	5	10		1	5	10
	1	5	5		2	4	8		1	6	12
	1	6	12		2	6	10		1	3	4
	1	4	7		2	5	10		1	5	14
132	2	6	13		2	6	11		1	6	13
	2	3	12		2	4	10		1	5	13
	2	4	8		2	1	7		1	6	11
	2	6	15		2	5	13		1	6	10
	2	5	9		2	6	14		1	5	8
	2	2	8		2	5	8		1	2	6
	2	6	12		2	6	13		1	5	10
	2	5	14		2	2	6		1	5	14
	2	3	9		1	4	12	135	2	5	13
	2	3	9		1	6	13		2	5	9
	2	6	14		1	5	11				

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
135	2	6	11	136	1	-	14	137	1	-	13
	2	6	11		1	-	15				
	2	5	10		1	-	9				
	2	6	10		1	-	10				
	2	2	10		1	-	14				
	2	2	3		1	-	11				
	2	4	11		1	-	14				
	2	6	9		1	-	14				
	2	6	10		1	-	12				
	2	5	10		1	-	10				
	2	6	11		1	-	7				
	1	5	9		1	-	7				
	1	6	15		1	-	10				
	1	4	10		1	-	8				
	1	6	15		1	-	9				
	1	5	11		1	-	3				
	1	5	8		1	-	7				
	1	5	10	137	2	-	10				
	1	5	10		2	-	9				
	1	5	12		2	-	8				
	1	5	12		2	-	12				
	1	6	14		2	-	10				
	1	5	11		2	-	6				
	1	6	12		2	-	10				
	1	5	11		2	-	13				
	1	2	4		2	-	13				
136	2	-	10		2	-	7				
	2	-	12		2	-	13				
	2	-	4		2	-	11				
	2	-	16		2	-	8				
	2	-	11		2	-	15				
	2	-	9		2	-	7				
	2	-	13		2	-	13				
	2	-	8		2	-	11				
	2	-	12		1	-	7				
	2	-	11		1	-	5				
	2	-	15		1	-	14				
	2	-	8		1	-	12				
	2	-	14		1	-	11				
	2	-	11		1	-	11				
	2	-	15		1	-	14				
	2	-	9		1	-	9				
	2	-	14		1	-	10				
	2	-	9		1	-	9				
	1	-	9		1	-	5				
	1	-	14		1	-	12				

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
231	2	5	11	232	2	6	12	233	1	6	12
	2	6	14		2	4	10		1	4	8
	2	6	8		2	4	10		1	6	6
	2	6	12		2	3	7		1	5	12
	2	3	8		1	4	10	234	2	3	8
	2	6	9		1	4	12		2	6	10
	2	4	10		1	5	11		2	5	11
	2	6	8		1	6	10		2	1	8
	2	6	8		1	5	9		2	4	10
	2	5	9		1	5	13		2	4	11
	2	3	11		1	5	12		2	5	10
	2	2	5		1	5	8		2	6	8
	2	5	10		1	6	9		2	5	9
	2	5	10		1	4	14		2	6	14
	2	6	11		1	6	9		2	6	6
	2	6	9		1	4	14		2	6	12
	2	5	10		1	6	7		2	6	12
	2	5	14		1	4	11		2	5	8
	2	5	11	233	2	6	12		2	3	6
	1	5	7		2	6	10		2	5	4
	1	5	11		2	5	11		2	6	8
	1	6	11		2	5	11		1	6	11
	1	5	8		2	5	9		1	4	9
	1	5	11		2	5	9		1	6	12
	1	6	9		2	3	10		1	6	14
	1	5	12		2	6	8		1	5	12
	1	6	12		2	6	10		1	6	10
	1	5	11		2	6	13		1	5	9
	1	4	6		2	5	11		1	5	10
	1	0	8		2	5	12		1	5	11
	1	4	11		2	3	5		1	4	4
	1	5	10		2	5	12		1	2	6
	1	4	6		2	6	12	235	2	4	5
232	2	6	10		2	4	8		2	6	9
	2	4	9		2	3	12		2	5	12
	2	5	14		2	5	10		2	5	11
	2	4	10		1	3	3		2	4	7
	2	4	8		1	4	10		2	6	13
	2	5	11		1	3	12		2	5	6
	2	3	9		1	5	13		2	6	6
	2	5	11		1	6	11		2	4	9
	2	6	11		1	4	4		2	5	6
	2	6	11		1	5	15		2	5	7
	2	5	6		1	4	10		2	6	13
	2	4	7		1	6	9				

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
235	2	4	8	236	1	-	6	331	2	3	12
	2	5	11		1	-	8		2	2	10
	2	5	7		1	-	13		2	6	16
	2	6	10		1	-	10		2	4	7
	2	6	10		1	-	3		2	4	14
	1	3	3		1	-	6		2	5	14
	1	3	8		1	-	10		2	4	7
	1	3	8	237	2	-	5		2	4	5
	1	2	6		2	-	12		2	5	10
	1	5	10		2	-	6		2	0	6
	1	5	12		2	-	8		2	2	5
	1	3	7		2	-	10		2	6	16
	1	5	13		2	-	3		2	3	11
	1	6	12		2	-	10		2	5	11
	1	5	8		2	-	11		2	3	8
	1	5	11		2	4	9		2	4	10
	1	6	9		2	-	13		2	1	6
	1	6	13		2	-	9		2	6	8
	1	5	12		2	-	11		2	5	16
	1	6	4		2	-	8		2	4	7
236	2	-	5		2	-	5		2	4	9
	2	-	12		2	-	6		2	5	15
	2	-	10		2	-	12		2	6	15
	2	-	10		2	-	7		2	6	16
	2	-	6		1	-	8		1	2	7
	2	-	9		1	-	9		1	4	8
	2	-	5		1	-	8		1	5	10
	2	-	7		1	-	11		1	4	8
	2	3	12		1	-	13		1	5	8
	2	-	8		1	-	10		1	1	6
	2	-	6		1	-	9		1	4	12
	2	-	11		1	-	13		1	5	15
	2	-	9		1	-	12		1	3	6
	2	-	13		1	-	13		1	6	15
	2	-	12		1	-	12		1	3	13
	2	-	10		1	-	13		1	4	11
	2	-	11		1	-	12		1	4	12
	1	-	13		1	6	10		1	3	4
	1	-	6	331	2	4	6		1	5	9
	1	-	10		2	2	8		1	5	13
	1	-	8		2	4	1		1	6	15
	1	-	9		2	6	16		1	4	15
	1	-	7		2	4	15		1	4	11
	1	-	12		2	2	9		1	4	5
	1	-	6		2	3	8	332	2	2	13
	1	-	12		2	4	11		2	6	13
	1	-	13		2	4	16		2	6	16
	1	-	13		2	4	7		2	1	5

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
332	2	4	11	333	1	4	5	335	2	0	2
	2	5	4		1	4	11		2	3	4
	2	4	14		1	5	9		1	6	11
	2	3	16		1	5	13		1	1	9
	2	6	9		1	5	10		1	2	6
	2	3	12		1	6	15		1	4	11
	2	2	9	334	2	6	12		1	6	15
	2	6	13		2	4	12		1	5	15
	2	5	14		2	5	13		1	4	12
	2	3	15		2	5	9		1	5	7
	2	3	6		2	2	5		1	5	7
	2	6	13		2	3	6		1	5	10
	2	3	7		2	3	9		1	2	5
	3	5	9		2	4	11		1	6	15
	2	4	8		2	3	4		1	4	13
	1	2	3		2	2	9		1	3	19
	1	5	14		2	4	10		1	1	5
	1	5	12		2	4	11		1	5	13
	1	5	9		2	2	8		1	0	10
	1	5	14		2	6	13	336	2	-	13
	1	4	11		2	5	9		2	-	6
	1	5	13		2	6	16		2	-	14
	1	5	14		2	5	13		2	-	11
	1	4	14		1	3	9		2	-	8
	1	4	15		1	3	5		2	-	11
	1	5	10		1	5	15		2	-	7
333	2	4	9		1	2	15		2	-	8
	2	5	9		1	6	13		2	-	16
	2	5	15		1	6	13		2	-	15
	2	5	11		1	2	11		2	-	8
	2	5	10		1	4	14		2	-	6
	2	5	16		1	4	9		2	-	15
	2	6	9		1	3	12		2	-	13
	2	6	16		1	4	6		2	-	13
	2	6	16		1	4	12		2	-	11
	2	2	5		1	3	10		2	-	12
	2	3	8	335	2	5	9		1	-	14
	2	3	6		2	3	11		1	-	11
	2	3	11		2	2	7		1	-	7
	2	4	5		2	3	14		1	-	8
	2	4	10		2	5	12		1	-	12
	2	4	8		2	6	13		1	-	13
	1	3	4		2	6	8		1	-	15
	1	4	15		2	5	13		1	-	12
	1	4	15		2	4	9		1	-	15
	1	4	11		2	6	13		1	-	16
	1	4	11		2	5	11		1	-	15

Table 24 (continued)

A	B	C	D
336	1	-	13
	1	-	12
	1	-	5
337	2	-	3
	2	-	11
	2	-	5
	2	-	4
	2	-	7
	2	-	13
	2	-	15
	2	-	12
	2	-	7
	2	-	8
	2	-	10
	2	-	11
	2	-	13
	1	-	8
	1	-	10
	1	-	7
	1	-	12
	1	-	4
	1	-	9
	1	-	14
	1	-	12
	1	-	8
161	2	6	4
	2	4	4
	2	8	9
	2	5	14
	2	6	9
	2	8	16
	2	7	15
	2	7	13
	2	7	16
	2	4	15
	2	5	4
	2	6	13
	2	6	13
	2	7	16
	2	8	9
	2	8	10
	2	6	4
	2	7	12

A	B	C	D
161	2	5	5
	2	2	2
	2	8	19
	2	7	16
	2	2	6
	2	3	12
	2	4	13
	2	7	12
	2	4	10
	2	6	9
	1	8	9
	1	7	16
	1	6	13
	1	7	16
	1	6	4
	1	6	2
	1	8	19
	1	3	12
	1	7	12
	1	4	10
162	1	8	14
	1	6	13
	1	8	15
	1	7	14
	1	8	15
	1	7	11
	1	6	7
	1	4	11
	1	7	17
	1	7	11
	1	8	13
	1	8	14
	2	2	14
	2	8	14
	2	7	17
	2	1	13
	2	7	11
	2	2	12
	2	4	14
	2	7	12
	2	7	11
	2	8	12
	2	8	17

A	B	C	D
162	2	4	8
	2	7	13
	2	6	14
163	1	8	12
	1	8	12
	1	5	7
	1	8	17
	1	6	8
	1	6	11
	1	8	17
	1	8	14
	1	8	20
	1	8	13
	1	3	12
	1	8	13
	2	6	14
	2	8	11
	2	7	16
	2	6	12
	2	5	8
	2	7	11
	2	4	16
	2	8	19
	2	8	9
	2	7	16
	2	7	13
	2	7	18
	2	8	16
	2	8	17
	2	8	13
164	1	8	15
	1	8	18
	1	1	13
	1	7	13
	1	7	16
	1	8	17
	1	7	10
	1	6	17
	1	7	14
	1	8	15
	1	8	15
	2	6	17
	2	4	10
	2	7	13

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
164	2	8	17	166	1	-	15	167	1	-	13
	2	4	6		1	-	13		1	-	3
	2	6	10		1	-	15		1	-	18
	2	7	8		1	-	12		1	-	11
	2	7	10		1	-	6		1	-	11
	2	8	18		1	-	11		1	-	16
	2	8	18		1	-	17		1	-	5
	2	8	17		1	-	13		1	-	15
	2	8	17		1	-	11		1	-	15
	2	8	14		1	-	13		2	-	11
	2	3	6		1	-	19		2	-	19
	2	6	3		1	-	17		2	-	13
	2	5	9		1	-	13		2	-	18
	2	5	17		1	-	7		2	-	8
	2	6	12		1	-	6		2	-	8
165	1	6	9		1	-	12		2	-	13
	1	5	10		1	-	11		2	-	9
	1	3	12		1	-	11		2	-	13
	1	4	11		1	-	14		2	-	17
	1	8	13		1	-	17		2	-	12
	1	8	16		2	-	11		2	-	17
	1	7	12		2	-	7		2	-	15
	1	6	12		2	-	15		2	-	18
	1	7	9		2	-	16		2	-	17
	1	7	5		2	-	20		2	-	14
	1	7	12		2	-	15		2	-	12
	1	7	10		2	-	12	261	2	6	13
	1	8	16		2	-	14		2	7	14
	1	8	17		2	-	9		2	8	13
	1	8	18		2	-	19		2	4	6
	1	7	16		2	-	12		2	8	6
	2	7	12		2	-	17		2	6	11
	2	6	9		2	-	16		2	8	16
	2	8	18		2	-	17		2	2	8
	2	8	19		2	-	12		2	6	9
	2	4	10		2	-	12		2	6	9
	2	5	12	167	1	-	14		2	5	12
	2	8	16		1	-	18		2	6	16
	2	8	17		1	-	18		2	4	16
	2	7	19		1	-	14		2	4	11
	2	6	12		1	-	11		2	8	13
	2	7	12		1	-	16		2	7	17
	2	0	15		1	-	17		1	8	16
	2	8	18		1	-	12		1	7	9
	2	7	12		1	-	15		1	8	10
	2	7	17		1	-	12				

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
261	1	7	8	263	2	7	10	265	1	6	13
	1	7	12		2	6	7		1	8	15
	1	7	16		2	7	14		1	7	16
	1	5	9		2	7	12		1	6	16
	1	6	10		2	8	15		1	8	19
	1	7	10		2	6	15		1	8	17
	1	8	13		1	7	14		1	6	15
	1	3	19		1	7	13		1	8	13
	1	6	7		1	8	12		1	5	9
	1	7	8		1	4	9		1	8	11
262	2	7	9		1	6	8		1	6	15
	2	8	18		1	5	16		1	4	16
	2	5	5		1	5	10		1	7	9
	2	6	17		1	6	10		1	6	14
	2	7	12		1	8	9		1	7	6
	2	2	5		1	5	6		1	8	16
	2	8	19		1	8	13		1	7	9
	2	7	14		1	4	8		1	5	13
	2	8	15		1	6	15		2	8	14
	2	2	6		1	6	11		2	5	14
	2	6	10	264	2	5	8		2	8	9
	2	3	4		2	5	5		2	7	17
	2	4	14		2	8	9		2	5	7
	2	7	14		2	4	11		2	7	16
	2	3	9		2	6	12		2	7	15
	2	5	14		2	6	11		2	6	9
	1	7	13		2	7	16		2	6	12
	1	7	18		2	6	14		2	8	10
	1	6	12		2	6	7		2	8	16
	1	6	13		2	6	17		2	7	14
	1	6	19		2	7	9		2	8	14
	1	7	12		2	5	14	266	1	-	9
	1	2	10		2	7	10		1	-	13
	1	6	9		2	8	20		1	-	17
	1	7	13		2	7	10		1	-	15
	1	4	2		2	8	18		1	-	12
	1	7	12		1	4	6		1	-	14
	1	8	9		1	5	4		1	-	13
	1	3	12		1	7	19		1	-	10
263	2	7	14		1	7	14		1	-	15
	2	8	14		1	8	0		1	-	13
	2	8	15		1	6	15		1	-	16
	2	3	11		1	8	15		1	-	14
	2	6	9		1	7	18		1	-	11
	2	7	14		1	6	9		1	-	9
	2	8	10		1	7	8		1	-	15
	2	4	11		1	7	18		1	-	17
					1	6	13				

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
266	2	-	14	361	1	6	10	363	2	6	6
	2	-	13		1	2	9		2	3	4
	2	-	15		1	1	9		2	5	14
	2	-	10		1	1	6		2	7	14
	2	-	10		1	5	9		2	1	9
	2	-	9		1	6	16	364	1	7	15
	2	-	14		1	5	9		1	7	16
	2	-	7		1	6	7		1	7	12
	2	-	11		1	2	9		1	4	16
	2	-	12		1	4	3		1	6	15
	2	-	4		1	7	12		1	3	14
	2	-	12		1	8	11		1	7	16
	2	-	14	362	2	7	12		1	3	8
	2	-	9		2	3	9		1	8	19
	2	-	13		2	7	16		1	1	9
	2	-	15		2	7	17		1	3	15
	2	-	17		2	8	15		1	6	17
	2	-	17		2	7	18		1	3	14
	2	-	17		2	2	6		1	4	11
267	2	-	8		2	4	11		2	7	11
	2	-	11		2	4	9		2	5	6
	2	-	11		2	6	16		2	6	7
	2	-	14		2	7	12		2	5	9
	2	-	14		2	8	5		2	4	3
	2	-	17		2	5	4		2	3	2
	2	-	15		2	8	12		2	7	11
	2	-	16		2	6	15		2	7	5
	2	-	16		2	7	17		2	6	16
	2	-	13		2	5	14		2	5	6
	2	-	16		2	8	8		2	2	4
	2	-	12	363	1	7	15		2	5	13
	2	-	15		1	7	9		2	6	9
	2	-	16		1	8	14		2	6	4
	2	-	8		1	5	10		2	2	18
	1	-	12		1	8	17		2	2	7
	1	-	16		1	8	17		2	8	16
	1	-	16		1	6	15	365	1	5	17
	1	-	14		1	4	16		1	7	7
	1	-	14		1	6	18		1	6	19
	1	-	18		1	7	3		1	7	15
	1	-	11		1	7	15		1	2	3
	1	-	10		2	7	16		1	3	11
	1	-	15		2	8	18		1	8	14
	1	-	2		2	5	15		1	7	19
361	1	7	18		2	7	15		1	5	12
	1	4	6		2	1	6		1	7	15
	1	6	17		2	3	9		1	7	16
	1	1	8		2	8	16		1	5	15
	1	5	13		2	7	11		1	0	10

Table 24 (continued)

A	B	C	D	A	B	C	D	A	B	C	D
365	1	6	16	366	2	-	13				
	1	7	19		2	-	9				
	1	4	2		2	-	15				
	1	6	10		2	-	13				
	1	8	15		2	-	11				
	2	6	13		2	-	17				
	2	2	6		2	-	15				
	2	4	6	367	2	-	13				
	2	6	16		2	-	7				
	2	5	17		2	-	11				
	2	5	15		2	-	7				
	2	5	8		2	-	13				
	2	4	15		2	-	3				
	2	7	10		2	-	17				
	2	4	15		2	-	12				
	2	6	16		2	-	7				
	2	0	18		2	-	16				
	2	8	19		2	-	18				
	2	8	12		2	-	10				
	2	7	4		2	-	8				
	2	7	16		2	-	10				
	2	5	13		2	-	17				
366	1	-	18		2	-	4				
	1	-	16		2	-	12				
	1	-	15		2	-	9				
	1	-	18		2	-	8				
	1	-	6		2	-	16				
	1	-	8		2	-	11				
	1	-	13		1	-	17				
	1	-	6		1	-	15				
	1	-	12		1	-	8				
	1	-	14		1	-	10				
	1	-	10		1	-	10				
	1	-	16		1	-	3				
	1	-	15		1	-	18				
	2	-	8		1	-	11				
	2	-	12		1	-	15				
	2	-	10		1	-	13				
	2	5	15		1	-	12				
	2	0	16		1	-	12				
	2	-	19		1	-	16				
	2	1	19		1	-	19				
	2	-	9								
	2	-	9								
	2	1	18								

TABLE 25

Criterion Test Scores

Experiment II - Physical Analogies

Treatment Groups		Control Groups	
Compression	Diffusion	Compression	Diffusion
13	12	6	9
8	9	15	5
14	12	11	13
13	16	10	9
8	12	6	18
11	13	9	7
7	17	12	7
8	17	12	19
6	11	6	10
11	15	9	10
9	15	7	9
12	9	4	6
9	12	5	10
3	16	16	6
5	15	12	14
7	7	9	14
7	8	7	5
17	13	3	8
8	12	12	12
10	15	12	9
11	17	5	13
13	12	-	9
-	17	-	11
-	4	-	15
-	17	-	-

Table 25 (continued)

Treatment Groups		Control Groups	
Compression	Diffusion	Compression	Diffusion
-	11	-	-
-	9	-	-
-	7	-	-
-	9	-	-
-	12	-	-
-	9	-	-
-	11	-	-
-	9	-	-

TABLE 26

Criterion Test Scores

Experiment III - Extended Verbal Analogy

Treatment Group	Control Group
6	9
8	11
6	10
9	9
10	10
11	10
7	8
9	13
8	9
13	10
8	8
11	8
7	11
15	8
9	9
10	10
8	13
10	11
8	11
8	12
4	9
11	11
11	9
6	10
13	7
11	13
9	7
8	8
10	9
8	6
5	8
8	9
8	10
9	11
14	6
10	7
15	10
10	14
11	7
12	7
	13

APPENDIX D

PILOT STUDIES

Four pilot studies were carried out in preparation for the present study. These are presented in turn below.

PILOT STUDY I

Problem

To determine the relative effectiveness of five different methods of presenting a scientific explanation to subjects.

Sample

The sample consisted to 133 seventh grade students from a Junior High School in Edmonton, Alberta.

Design

Treatments

Control Treatment. A scientific explanation concerning the classification of matter and chemical change was written. The length of the scientific explanation was 823 words. The scientific explanation was written in a clear, concise manner without employing any

analogies, examples,advance organizers or physical models. Four other treatments were generated from the scientific explanation as follows.

Example treatment. Examples were inserted into the scientific explanation at appropriate points.

Verbal analogy treatment. The primary field of a conceptual verbal analogy was inserted into the scientific explanation by presenting a paragraph of scientific explanation and then the corresponding paragraph of the primary field. Paragraphs of the scientific explanation and primary field were alternated in this order throughout the passage.

Physical analogy treatment. The scientific explanation was accompanied by a display board on which the various classes of matter were displayed using physical objects (coloured stryofoam spheres). The display board was readily visible to subjects while they were reading the scientific explanation.

Advance organizer treatment. Two days before subjects read the scientific explanation they were presented with an advance organizer related to the scientific explanation.

Criterion Test

The criterion test consisted of fifteen multiple choice items each having one correct answer and three distractors.

Procedure

Subjects were randomly assigned to treatment groups. Subjects who were assigned to the Advance Organizer treatment group were administered the advance organizer two days before they read the scientific explanation and responded to the criterion test on the test day. Subjects in the Examples and Verbal Analogy treatment groups read the passages associated with their treatments and immediately responded to the criterion test. Subjects in the Physical Analogy treatment group sat as a group in a corner of the room and were asked to read the scientific explanation and refer to the display board as they were reading. The display board was positioned so that only the subjects in the Physical Analogy group would see it. After reading the scientific explanation and studying the display board, the Physical Analogy subjects responded to the criterion test.

Analysis of Data

A 2 x 5 (sex x treatment) fixed effect factorial design was employed for the analysis of the criterion test scores under the null hypothesis: there are no significant differences between sexes among treatments and there is no significant sex x treatment interaction effect.

Results

The summary table for the analysis of variance is presented in Table 27. The analysis indicates that there was a significant sex main effect and a significant treatment main effect.

Analysis of the sex main effect indicates that females scored significantly higher on the criterion test than males.

Analysis of the treatment main effect using Scheffes multiple comparisons test indicates that the mean for the Verbal Analogy treatment group was significantly lower than the means for both the Advance Organizer and the Physical Analogy treatment groups.

Discussion

It would appear that females tend to understand the passage significantly better than males for all treatments.

While the mean for the Verbal Analogy treatment is significantly less than the means for the Advance Organizer and Physical Analogy treatment, it is not significantly less than the mean for the Control treatment in which the subjects read only the scientific explanation.

The results of this experiment indicate that the use of examples, an advance organizer or a physical analogy does not significantly increase immediate comprehension of a scientific explanation over that obtained when only the scientific explanation is read. However, the use of an advance organizer or a physical analogy appeared to be significantly superior to the use of verbal analogy in increasing comprehension

TABLE 27

Pilot Study I

Summary of Two-Way Analysis of Variance:
Sex x Treatment

Source	SS	DF	MS	F-Ratio	p
Sex	51.7	1	51.7	8.46	.004
Treatments	98.2	4	24.6	4.02	.004
Sex x Treatment	11.4	4	2.86	.468	.760
Error	751.2	123	6.11		

B. Cell Means and Frequencies

	Control	Verbal Analogy	Examples	Advance Organizer	Physical Analogy
Female	8.2 (12)	6.4 (12)	7.7 (14)	8.6 (10)	9.2 (13)
Male	7.4 (14)	5.3 (15)	6.5 (14)	7.9 (14)	6.9 (15)

of a scientific explanation. However, an analysis of reading scores for the subjects in the verbal analogies group indicated that their average percentile rank on the S.T.E.P. reading test was 34.2 as compared with 44.6 for the Advance Analogy and Physical Analogy groups. It would appear that the significant differences between the Verbal Analogy group and the other two groups may be due to sampling error.

PILOT STUDY II

Problem

To determine whether the use of a concrete verbal analogy in a scientific explanation will significantly increase immediate comprehension of a scientific explanation over that obtained when only the scientific explanation is read.

Sample

The sample consisted of 391 ninth grade students from a Junior High School in Edmonton, Alberta.

Design

The design of this pilot study consisted of presenting primary field of a concrete verbal analogy in the "Pre", "Post", "Within" and "SxS" formats as defined in Experiment I of the present study. A fifth treatment consisted of administering an Advance Organizer two days before the scientific was read. A sixth treatment group, the "Control" group, read only the scientific explanation. A short (approximately 150 words)and a longer (approximately 300 words) scientific explanation was written for each of three topics. A primary field of a concrete verbal analogy and Advance Organizer was written for each of the six scientific explanations. The scientific explanations and primary fields differed from those used in Experiment I only to a minor degree in wording.

A modified Cloze Test was constructed for each of the six scientific explanations by removing certain key words from the scientific explanations. These tests were used as the criterion tests.

This design resulted in six, one-way analysis of variance designs having six treatment groups.

Procedure

The procedure used for this pilot study was similar to that of Experiment I, except no distinction was made between sexes and subjects were not allowed to refer to the scientific explanations

while responding to the criterion tests. The advance organizer was administered in the same way as the advance analogy in Experiment I.

Results

The results were analyzed using six, one-way analysis of variance designs under the hypothesis: there is no significant difference in criterion score means among formats.

The results of six analyses of variance are presented in Tables 28 and 29.

The results indicate that the null hypothesis was rejected in only one of the six cases. It was rejected for the longer Phase Change scientific explanation. The Neuman-Keuls test for differences between means indicated the "Pre" format treatment group mean was significantly less than the other five treatment group means.

A comparison of the numerical values of the different treatment group means in which an analogy was employed with their respective control group means indicates that, in general, the treatment group means are less than the control group means. The "Advance Organizer" treatment group means are similar to the corresponding "control" group means in all six cases.

It appears that the use of a concrete verbal analogy in a scientific explanation does not increase immediate comprehension of the scientific explanation when a modified Cloze Test is the criterion test.

TABLE 28

Pilot Study II: Summary of One-Way Analyses of Variance, Cell Means and Frequencies of Cloze Scores for Short Scientific Explanations

A. Analyses of Variance

(i) Phase Change

Source	SS	df	MS	F-Ratio
Format	105.5	5	21.1	2.24 ($p > .05$)
Error	603.3	64	9.43	

(ii) Compression

Source	SS	df	MS	F-Ratio
Format	14.28	5	2.86	0.41 ($p > .05$)
Error	435.7	63	6.91	

(iii) Diffusion

Source	SS	df	MS	F-Ratio
Format	191.3	5	38.26	2.41 ($p > .05$)
Error	968.5	61	15.88	

B. Cell Means and Frequencies

Format	Phase Change	Compression	Diffusion
Pre	18.8 (8)	22.6 (10)	21.6 (8)
Post	19.1 (7)	22.8 (10)	20.0 (7)
Within	18.3 (10)	22.1 (6)	20.6 (8)
SxS	19.5 (5)	23.0 (8)	16.5 (10)
Adv. Organizer	21.0 (8)	24.0 (6)	20.5 (5)
Control	21.3 (26)	23.1 (23)	21.1 (23)

TABLE 29

Pilot Study II: Summary of One-Way Analyses of Variance, Cell Means and Frequencies on Cloze Scores for Longer Scientific Explanations

A. Analyses of Variance

(i) Phase Change

Source	SS	df	MS	F-Ratio
Format	517.6	5	103.5	5.27 ($p < .05$)
Error	1042.1	53	19.66	

(ii) Compression

Source	SS	df	MS	F-Ratio
Format	69.18	5	13.84	1.36 ($p > .05$)
Error	537.5	53	10.1	

(iii) Diffusion

Source	SS	df	MS	F-Ratio
Format	289.8	5	57.97	2.36 ($p > .05$)
Error	1496.8	61	24.5	

B. Cell Means and Frequencies

Format	Phase Change	Compression	Diffusion
Pre	19.1 (7)	27.7 (6)	23.0 (9)
Post	28.9 (8)	28.3 (7)	23.9 (10)
Within	26.0 (6)	28.1 (8)	[illegible].1 (7)
SxS	25.4 (7)	26.1 (6)	[illegible].5 (5)
Adv. Organizer	28.3 (7)	29.4 (6)	[illegible] (8)
Control	27.1 (18)	29.4 (20)	[illegible] (22)

PILOT STUDY III

Problem

To refine the test instruments to be used in Experiment I and to compare immediate comprehension obtained when a scientific explanation is presented with and without a concrete verbal analogy.

Sample

The sample consisted of 238 tenth grade subjects enrolled in a first year chemistry course in a senior high school in Edmonton, Alberta.

Design

Treatments

The argument rank six scientific arguments, primary fields and the postulates of the Kinetic Molecular Theory used in Experiment I were used as the treatments for this pilot study. The criterion and analogy tests used were unrefined forms of those used in Experiment I. Each subject in one of the three experimental groups was administered a test booklet containing the postulates of the

Kinetic Molecular Theory, one of the scientific explanations, its corresponding primary field and the corresponding analogy and criterion test in the order mentioned. The booklets were randomly administered to subjects in five classes. After students had completed the tests a questionnaire was administered to each subject to determine whether they felt that the presence of the analogy had aided them in understanding the scientific explanation. One week later, the same scientific explanations and their corresponding tests without the postulates or the primary fields were administered randomly to three different classes within the same school to ensure that the test scores for the control groups were also normally distributed.

Procedure

Test booklets were distributed randomly to subjects on the two testing days. After filling out the heading of the answer sheets and carefully reading the test instructions, subjects were told that they could refer to the passages if they wished while responding to the test items. Upon completing the tests, subjects were given the questionnaires to complete.

The answer sheets were marked and items analysis was carried out and the results of the questionnaires were compiled. While the groups which were administered the scientific explanation and the

corresponding tests without the postulates or primary field could not properly be used as a control group, a comparison of their criterion score means was made with those of the corresponding treatment groups.

Results

The results of the experiment indicated that a number of test items required revision. Analysis of the questionnaire data indicated that seventy-nine percent of the subjects who were administered primary fields along with the scientific explanation indicated that they felt that the presence of the primary field had helped them understand the scientific explanation better than they would have if the primary field was not present.

A comparison of the criterion score means are presented in Table 30. These results indicate that in each case the mean of the groups which read only the scientific explanation was numerically greater than the groups which read the postulates of the Kinetic Molecular Theory, the scientific explanation and the verbal analogy. In the case of the Phase Change scientific explanation the group which read the scientific explanation only, scored significantly higher than the group which read the postulates of the Kinetic Molecular Theory, the scientific explanation and the primary field of a concrete verbal analogy.

TABLE 30

Pilot Study III: Summary of t-Test Results for Concrete Verbal Analogies

A. Phase Change

	Treatment Group: Scientific Explanation with Analogy (N = 48)	Control Group: Scientific Explanation Only (N = 32)
Criterion Mean	12.5	14.5
Variance	11.87	8.00

df = 78

t = 2.81 ($p < .05$)

B. Compression

	Treatment Group: Scientific Explanation with Analogy (N = 45)	Control Group: Scientific Explanation Only (N = 31)
Criterion Mean	10.9	12.1
Variance	10.90	12.70

df = 74

t = 1.44 ($p > .05$)

C. Diffusion

	Treatment Group: Scientific Explanation with Analogy (N = 52)	Control Group: Scientific Explanation Only (N = 30)
Criterion Mean	10.9	11.3
Variance	8.62	11.89

df = 80

t = .62 ($p > .05$)

Summary

It appears that subjects feel that the use of a concrete verbal analogy in a scientific explanation aids them in understanding the scientific explanation. However, on the basis of the data obtained in this experiment, it would appear that empirical data do not support their feelings.

PILOT STUDY IV

Introduction

Pilot Study IV was designed to examine a number of variables related to Experiment I. The testing materials employed in this pilot study were identical to those used in Experiment I.

Problem

To determine:

1. The effect on immediate comprehension when the primary field of a concrete verbal analogy and the postulates of the Kinetic Molecular Theory are administered two days before the scientific explanation is read.

2. Whether there is a difference in immediate comprehension when subjects are allowed to refer to the scientific explanation and primary field when responding to the analogy and criterion test as opposed to not allowing students to refer them.

3. Whether subjects could respond correctly to the criterion tests without having read the scientific explanations.

4. Whether subjects could respond correctly to the analogy tests items even if they had not read the primary or secondary fields of the analogies.

Design

Sample. The sample consisted of 337 tenth grade students enrolled in an introductory chemistry course in a senior high school in Edmonton, Alberta.

Treatments

Two days before the testing day the postulates of the Kinetic Molecular Theory and the primary fields for the argument rank six Phase Change and Diffusion passages were administered at random to sixty-six subjects. Those subjects not receiving one of these treatments were administered the placebo. On the test day those subjects who had received either the postulates or the primary field

were administered the corresponding scientific explanation, analogy and criterion tests. The remaining subjects were administered the following treatments.

The Phase Change and Diffusion scientific explanations and their corresponding criterion tests were administered to fourteen and fifteen subjects, respectively, with instructions that they were to read and study the scientific explanation and then respond to the criterion test without referring to the scientific explanation.

The Phase Change and Diffusion criterion tests were administered to nine, and eight subjects, respectively, who had read neither the scientific explanation nor the corresponding primary field.

Twenty-seven subjects were administered the Phase Change Analogy test and thirty subjects were administered the Diffusion analogy test without having read the primary or secondary fields of the analogy.

The scientific explanations and criterion tests for the Phase Change and Diffusion scientific explanations were administered to twenty and twenty one subjects, respectively, with instructions that they could refer to the scientific explanation while responding to the criterion test.

Results

The results of this pilot study are presented in Tables 31, 32 and 33. The means for the Phase Change and Diffusion groups which read the primary field two days before reading the scientific explanation are significantly greater than the corresponding means of the groups which read only the scientific explanation.

TABLE 31

Results of Pilot Study IV

Test Means

Treatments	Phase Change	Diffusion
Primary field administered two days before scientific explanation read	15.2	14.5
KMT administered two days before scientific explanation read	12.1	13.0
Scientific explanation read but subjects not allowed to refer to explanation while responding to test	12.1	14.6
Criterion test done without reading primary or secondary field of analogy	8.8	8.3
Criterion test done after reading scientific explanation and primary field	13.0	12.2
Analogy test done without reading primary or secondary field of analogy	4.6	3.5
Analogy test done after reading primary and secondary field of analogy	7.3	5.7

TABLE 32

Results of t-Tests for Experiments in Pilot
Study IV: Phase Change

A. Advance Concrete Verbal Analogy

	Primary Field Read Two Days Before Scientific Explanation (N = 20)	Only Scientific Explanation Read (N = 13)
Criterion Means	15.4	13.0
Variance	6.92	13.62

df = 31
t = 2.06 ($p < .05$)

B. Advance Conceptual Verbal Analogy

	Postulates of KMT Read Two Days Before Scientific Explanation (N = 19)	Only Scientific Explanation Read (N = 20)
Criterion Means	12.7	13.0
Variance	17.77	12.95

df = 37
t = 0.16 ($p > .05$)

C. Referral to Scientific Explanation During Testing

	Subjects Not Allowed to Refer to Scientific Explanation While Responding to Criterion Test (N = 14)	Subjects Referred to Scientific Explanation While Responding to Criterion Test (N = 20)
Criterion Means	12.2	13.0
Variance	13.02	1[illegible]

df = 32
t = .57 ($p > .05$)

Table 32 (continued)

D. Criterion Test Written With and Without Having Read Scientific Explanation

	Subjects Did Not Read Scientific Explanation (N = 9)	Subjects Read Scientific Explanation (N = 20)
Criterion Means	8.67	13.0
Variance	2.22	13.62

df = 27

t = 5.68 ($p < .0005$)

E. Analogy Test Written With and Without Having Read Analogy

	Subjects Did Not Read Analogy (N = 12)	Subjects Read Analogy (N = 23)
Analogy Test Means	4.7	7.3
Variance	0.61	3.95

adjusted df = 31

t' = 5.60 ($p < .0005$)

TABLE 33

Results of t-Tests for Experiments in Pilot Study IV: Diffusion

A. Advance Concrete Verbal Analogy

	Primary Field Read Two Days Before Scientific Explanation (N = 14)	Only Scientific Explanation Read Read (N = 21)
Criterion Means	14.5	12.3
Variances	10.12	18.51

df = 33

t = 1.65 ($p < .05$)

B. Advance Conceptual Verbal Analogy

	Postulates of KMT Read Two Days Before Scientific Explanation (N = 20)	Only Scientific Explanation Read (N = 21)
Criterion Means	13.0	12.3
Variances	18.23	17.56

df = 39

t = .56 ($p > .05$)

C. Referal to Scientific Explanation During Testing

	Subjects Not Allowed to Refer to Scientific Explanation While Responding to Criterion Test (N = 15)	Subjects Referred to Scientific Explanation While Responding to Criterion Test (N = 21)
Criterion Means	14.73	12.3
Variances	11.29	17.56

df = 34

t = 1.88 ($p > .05$)

Table 33 (continued)

D. Criterion Test Written With and Without Having Read Scientific Explanation

	Subjects Did Not Read Scientific Explanation (N = 8)	Subjects Read Scientific Explanation (N = 21)
Criterion Means	8.3	12.3
Variances	3.42	17.56

df = 27

t = 3.44 ($p < .005$)

E. Analogy Test Written With and Without Having Read Analogy

	Subjects Did Not Read Analogy (N = 30)	Subjects Read Analogy (N = 13)
Analogy Test Means	3.5	5.70
Variances	2.53	1.73

df = 41

t = 4.29 ($p < .0005$)

The means for the Phase Change and Diffusion groups which read the postulates of the Kinetic Molecular Theory two days before reading the scientific explanation and the means for the Phase Change and Diffusion groups which were not allowed to refer to the corresponding scientific explanation while responding to the criterion tests were not significantly different from their corresponding control groups which read only the scientific explanation and were allowed to refer to it while responding to the criterion tests.

The means for both the Phase Change and Diffusion criterion tests when done without subjects having read the scientific explanation were significantly less than the corresponding means of the groups which read the scientific explanation before responding the criterion tests. Furthermore, the means for the groups which responded to the criterion test without having read the scientific explanation were only slightly greater than the chance level of 9.62.

The means for the analogy tests for the Phase Change and Diffusion analogies when the test was done without the subjects having read the analogies were significantly less than the corresponding means obtained when subjects had read the analogies. The mean for the Phase Change analogy test was just above the chance level while the mean for the Diffusion analogy test was within the chance level.

<u>Discussion of Results</u>

Since the advance position for the primary field of the concrete verbal analogies both resulted in a significant increase in immediate comprehension over that obtained by their corresponding control groups, it was decided to include this format in Experiment I. Furthermore, it was decided to administer the postulates of the Kinetic Molecular Theory in the advance format since the advance format appeared to be optimal in terms of increasing immediate comprehension for the concrete verbal analogy. Also, presenting both types of analogy in the advance format would enable a comparison to be made between the effects of a concrete verbal analogy and a conceptual verbal analogy on immediate comprehension.

Since no significant difference for either scientific explanation was noted between the means of subjects who were allowed to refer to the scientific explanation and those who were not allowed to refer to it while responding to the criterion test and since in most learning situations when a student is using a textbook to learn new learning material the student is free to refer to the written text while responding to a set of questions, it was decided to allow subjects to refer to the scientific explanation while responding to the criterion test in Experiment I.

The low mean scores on the criterion tests obtained by the group of subjects who had not previously read the scientific explanations indicated that subjects were not very familiar with

the content of the scientific explanations before they had read them. This finding indicated that the scientific explanations constituted new learning material to the subjects. Furthermore, the significant differences noted for both scientific explanations between the means of those subjects who read the scientific explanation and that of those who had not read it indicated that reading the scientific explanation resulted in learning. This indicated that the new learning material was not beyond the level of comprehension of the average subject. In summary, it would appear that the two scientific explanations can correctly be labelled as new learning material of the nature that subjects would encounter in a regular classroom learning situation.

The finding that subjects who had not read the analogies scored near the chance level on the analogy tests indicated that subjects were not able to respond correctly to the items of the analogy test by simple association or by some other means. Since all of the subjects who read the Phase Change analogy met the criterion set for passing the analogy test (the criterion was set at a score of greater than or equal to six correct responses out of the eight items) and ten of thirteen subjects met this criterion for the Diffusion analogy, it appeared that comprehension of the analogies was well within the ability of the subjects. Those who had read the analogies scored significantly higher on the analogy test than those who had not read it. This indicated that reading of the analogy enabled subjects to learn it.